Study Element Report

SURFACE AND GROUND

WATER RESOURCES

HAWAII WATER RESOURCES REGIONAL STUDY

Honolulu, Hawaii

STUDY ELEMENT REPORT

SURFACE AND GROUND WATER RESOURCES

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Hawaii Water Resources Regional Study

Honolulu, Hawaii
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SUMMARY

Rainfall in the Region averages about 70 inches per year, and, except in the smaller islands that lie in the lee of larger, higher islands, results in water resources adequate to meet most needs. However, largely because of the unequal areal distribution of the rainfall, there are areas of excess water and areas of deficient water even on the larger islands. The solution to water problems, therefore, often involves the collection and diversion of water in the wetter areas and the transmission to and distribution of the water in the drier areas.

Surface-water supply systems have been based upon the use of dry-weather flow with very little dependence on storage; owing to steep topography and usually porous surface rocks, sites for economical storage of surface water are scarce in the wetter areas. Consequently, much surface water flows to sea unused whenever diversion capacities are exceeded.

Ground-water supplies are being developed more and more for domestic, for industrial, and even for agricultural use because of the unreliability of surface-water supplies, which depend so much on the vagaries of rainfall. Basal water, which floats upon salt water, is the most widespread source of ground water and occurs under all the islands. Dike water, because of its extent and the altitudes where it occurs, is an extremely valuable source. Perched water is also valuable, but is usually limited in quantity.

Surface water is usually low in mineral content because rainfall is the primary source of surface and ground waters, and streams are short and steep. However, during rains, overland flow can wash significant amounts of bacterial contaminants into the streams. Ground water, especially basal water, contains a higher mineral content because of the length of time that it remains in contact with soluble minerals before its use. Bacterial contamination of ground water has not been detectable.

In 1970 (according to U.S. Geol. Survey Circ. 676), 140 mgd (million gallons per day) of fresh water was used for public supplies, 1,300 mgd for irrigation, and 390 mgd for industrial purposes within the Region.

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INTRODUCTION

Purpose

This study element report describes the nature and occurrence of the surface- and ground-water resources of the Region. The data and interpretations presented should be useful for the planning of orderly development of the water and land resources.

Scope

The water resources of this Region are described in this study element report. The close relationship of rainfall and streamflow is noted--in general, streamflow is large and perennial where rainfall is high. The geology of the Region is briefly described, especially as it affects the modes of occurrence of surface and ground waters. One effect of geology on streamflow is that in certain areas of high rainfall, streamflow is not perennial because the surface rocks are fresh and extremely porous and soaks up all except exceptionally heavy rains. In such areas, ground-water recharge is high.

Available information on the quality of surface and ground waters is summarized.

Data Availability

Extensive water-resource data have been collected and compiled by federal, state, and local governmental agencies, and by private corporations. Systematic streamflow-data collections began in 1909, under an agreement between the U.S. Geological Survey and the Territory of Hawaii. The early programs were aimed primarily at obtaining reliable information about the existing water supply, both developed and undeveloped, for agricultural needs.

Coverage was later widened to include streams in remote areas where development was foreseen. Consequently, areal coverage, while still inadequate for a complete appraisal, is fairly extensive.

Ground-water data collection, at the beginning, was limited to the measurement of spring discharges. However, with the drilling of the first artesian well in the Ewa area in Oahu in 1879, the development of ground water for irrigation became important. Unfortunately, careful records of heads, pumpage, and water quality were not regarded as very important until about 1926 when people became concerned about an alarming decrease in artesian head. Data collection was intensified, and controls were effected.

Partly because of the general excellent quality of both surface and ground waters, which exceeded the criteria for most uses, little effort was expended in the earlier years to collect basic quality-of-water data. This attitude has changed in recent years in light of the emphasis placed upon environmental and esthetic characteristics of water. Beginning in 1970, water from selected representative streams in each of the major islands has been sampled during wet and dry periods.

REGIONWIDE VIEW

Geology

Volcanic Origin - Dikes and Flows

The Hawaiian Archipelago, which makes up the region, is a chain of volcanic islands built over a fissure 1,500 miles long in the floor of the Pacific Ocean. The eight major islands are tops of enormous shield volcanoes, which project high above the level of the sea in the southeastern end of the chain. Each of the major islands consists of one to five volcanic domes, the bulk of which are composed of thousands of generally thin-bedded, highly vesicular basaltic lava flows. The structural features generally associated with these flows, such as an abundance of clinker sections, voids between flow surfaces, and shrinkage joints and fractures, make these rocks highly porous and pervious. The lavas issued in repeated outpourings from narrow zones of fissure associated with each volcano. When volcanic activity ceased, lava remaining in the fissures was quickly chilled by the surrounding rock and filled the fissures with narrow vertical sheets of rock with low permeability, called dikes. This rock assemblage of highly permeable basaltic-lava flows, intruded in part by dikes in the rift zones and free of dikes outside the rift zones, makes up the principal aquifer in the Hawaiian Islands.

Toward the end of the initial mountain-building phase, the tops of most Hawaiian shield volcanoes collapsed to form calderas. Lavas that subsequently ponded in the calderas were thicker, more massive and much less permeable than those that were extruded on the flanks outside the calderas. The ponded lava flows are poor aquifers.

Some volcanic eruptions were moderately explosive because of the steam formed when hot magma (molten rock) encountered ground water close to land surface. In these eruptions, the magma was exploded into tiny fragments and droplets, which hardened in the air to form particles of glassy volcanic ash. The finer ash was scattered widely and was usually altered to form extensive sheets of less permeable material. Where these deposits are covered by subsequent, more permeable lava flows, they act as perching members for ground water.

The last stage of the initial mountain-building phase usually consisted of the capping and burying of the earlier-formed basaltic shield volcano by more siliceous lava flows of andesite. The andesite cap is absent from basaltic flows that make up the Koolau, Kilauea, and Mauna Loa volcanoes. The andesitic flows were more viscous than the basaltic flows and consequently thicker and more massive and less permeable and, except locally, are not important aquifers. The structural features generally associated with the highly permeable basaltic flows, such as clinker sections, voids, and shrinkage joints, are much less extensive in the andesitic flows. The andesitic flows, although widespread, do not generally extend below sea level, except near the coast.

The initial mountain-building phase was followed by a very long period of volcanic quiescence and deep valleys were formed by erosion. This period was followed by a period of great submergence and, in most volcanoes, a resumption of volcanic activity. The lavas of this post-erosional period erupted basalts which are less siliceous than the early basalts, as well as trachytes, which are more siliceous and viscous than the andesites. These post-erosion lavas, although highly permeable in some areas, are not very extensive below sea level, and, therefore, are not important aquifers, except locally.

A diagrammatic cross section showing the geologic structure of a typical Hawaiian volcanic island in the form of an idealized volcanic dome is shown (fig. 1).

The general character of the common volcanic rocks and their water-bearing properties are summarized in table 1.

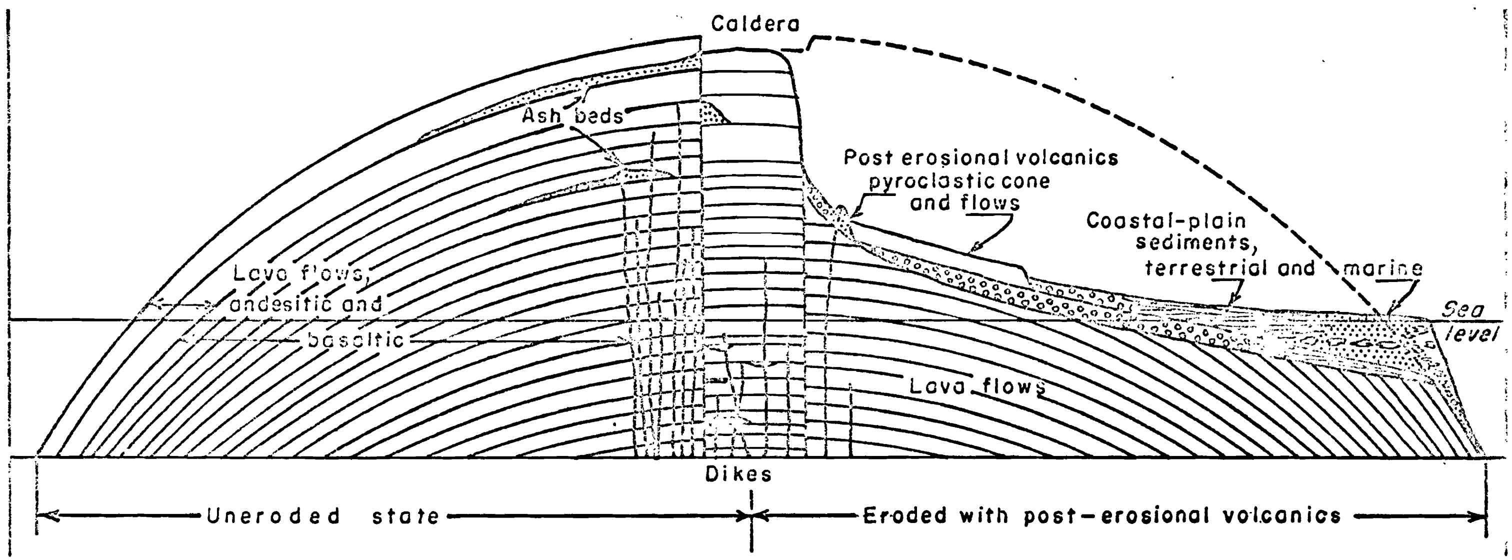


Figure 1. Diagrammatic cross section showing geologic structure of an idealized Hawaiian volcanic dome (after Cox, 1954).

Table 1. Common volcanic rocks and their water-bearing properties

Rock assemblage	General character	Water-bearing properties
Lava flows		
Basalts outside caldera	Thin-bedded highly vesicular flows in flanks of all volcanoes. From bulk of islands but may be covered by later flows.	Highly permeable and are the principal aquifers on all islands. When intruded by dikes, contain important sources of ground water at high levels.
Basalts inside caldera	Massive ponded flows, generally in high mountainous areas.	Poorly permeable, not an important aquifer. Low infiltration promotes swamps in some areas.
Andesites	Mostly thick-bedded massive flows. Widespread but do not generally extend below sea level, except near shore.	Poorly to fairly permeable. Carry perched water in rainy areas and basal water near shore. Not important aquifer, except locally.
Nepheline-melilite basalts	Posterosional flows. Massive where ponded in depressions and valleys, otherwise thin-bedded in flanks of volcanoes. Generally do not extend below sea level, except near shore.	Highly permeable in flanks where flows are thin-bedded. Poorly permeable, where ponded. Not an important aquifer, except locally.

Table 1. Common volcanic rocks and their water-bearing properties (continued)

Rock assemblage	General character	Water-bearing properties
Intrusives (sub-aerially cooled)		
Dikes, sills	Mostly vertical sheets as dikes intruding lava flows. Numerous in calderas and rift zones, where the mountain-building basaltic lava flows are exposed. Sparse in andesitic and nepheline-melilite basaltic flows.	Poorly permeable. Generally impound ground water at high levels on all islands. Major aquifer, where basaltic flows outside calderas are intruded.
Pyroclastics (aerially ejected)		
Cinders	Friable or firmly compacted beds in cones, spatter, and thin layers of scoriaceous lava.	Highly permeable when unweathered but usually quickly drained after rains. Carry small perched-water bodies on intercalated soil layers in wet areas.
Ash	Friable deposits blown from cones by the wind.	Poorly permeable. Contains no water but acts as perching member for overlying permeable rock.
Tuff	Cemented volcanic ash.	Poorly permeable. Acts as perching member. Some water in fractures. Not an important aquifer.

Alluviation and Coral Reef (Caprock)

The general cause of alluviation and the formation of coral reefs in the Hawaiian Islands was a rise in sea level in relation to the land mass. Rises in the sea-level datum resulted partly from subsidence of the islands owing to their great uncompensated weight on the earth's crust and partly from the return of water to the oceans from melting continental glaciers.

A rise in sea-level datum causes alluviation by flattening stream gradients and decreasing the power of the streams to transport sediments. A fall in the datum would rejuvenate the streams and restore erosion.

Reef coral grows only in shallow water; therefore, thick coral reefs are a result of an accumulation of coral growing and keeping up with a rising sea-level datum. Remains of coral reefs found at great depths in well borings are indications of past lower stands of the sea. In contrast, remains of coral reefs found above sea level are indications of past higher stands of the sea.

In Hawaii there are isolated deposits of alluvium and talus in the lower and middle reaches of stream valleys, but most sedimentary deposits, both terrestrial and marine, are found in the coastal plain. Terrestrial sediments consist of talus, older and younger alluvium, and clay. Older alluvium is moderately to well consolidated and is generally found underlying the more poorly consolidated younger alluvium. Marine sediments consist of coral reef deposits and sand derived from coral and sea shells.

The sediments range from nearly impermeable clay to highly permeable beach sand and coralline deposits. Where permeable, in the coastal-plain areas, they are important local sources of agricultural, recreational, and cooling waters. Where impermeable in the higher altitudes, they act as perching members for permeable overlying rocks or, in the coastal plain, act as a confining member to form artesian conditions for ground water in the underlying permeable fresh lava. The poorly permeable combination of terrestrial and marine sediments and weathered lavas that constitute the confining member in the coastal plain is known locally as caprock.

The general character of the common sedimentary rocks and their water-bearing properties are summarized in table 2.

Table 2. Common sedimentary rocks and their water-bearing properties

Rock assemblage	General character	Water-bearing properties
Marine sediments		
Coralline deposits	Chiefly coral reefs and coral rubble. Most extensive in coastal plains in Oahu, where deposits are found on the surface and at all depths down to about 1,000 feet but are most extensive to a depth of about 300 feet.	Fairly to highly permeable. More permeable when fractured and cavitated. Less permeable when rubbly. Contain water ranging from fresh to saline. Imporant aquifer for irrigation, recreation, and cooling waters. Easily recharged at surface or in the subsurface by the return of irrigation or heater waters.
Calcareous dunes		
Consolidated	Thin-bedded and cross-bedded deposits of sand blown inland from ancient beaches.	Fairly permeable, where there are sufficient solution channels. Not a domestic source or important aquifer, except locally. Brackish near shore.
Unconsolidated	Sand blown inland from present beaches.	Highly permeable but contains only brackish to saline ground water.
Beach sand	Derived from coralline deposits and sea shells. Occasionally mixed with cinders or tuff from nearby cones.	Highly permeable but contains only saline ground water.

Table 2. Common sedimentary rocks and their water-bearing properties (continued)

Rock assemblage	General character	Water-bearing properties
Marine sediments (cont.)		
Calcareous mud	Shallow lagoonal deposits.	Poorly permeable.
Terrestrial sediments		
Talus	Mainly unconsolidated gravel and boulders.	Highly permeable, but quickly drained after rains because storage is generally small.
Older alluvium	Moderately to well-consolidated and weathered in its entirety.	Poorly permeable. Acts as confining or perching member. Where it overlies or underlies, more permeable saturated rocks.
Younger alluvium	Reworked older alluvium in and near stream channels and overlying older alluvium.	Poorly to moderately permeable. Yield from wells is small but quality is generally good even near the coast.
Clay	Mainly shallow lagoonal deposits of stream-transported mud and silt.	Poorly permeable. In combination with weathered lavas, confine ground water underlying coastal plains in fresh-lava aquifers.

Rainfall

Rainfall is the principal source of all the fresh water in Hawaii, and its variability determines, directly or indirectly, the variability of occurrence of water in different parts of the islands. The occurrence and variability of rainfall are described more fully in the section on climatology, but some factors pertinent to water occurrence are mentioned here.

Mean annual rainfall ranges from 6.5 inches at Kawaihae, Hawaii to more than 450 inches at Waialeale on Kauai. On each of the major islands average rainfall ranges from less than 20 to more than 250 inches per year. Rainfall is generally greater on the windward side of mountains than on the leeward side. On islands where the highest elevations are less than 6,000 feet above mean sea level, the rainiest areas are along or near the crestline. On the large, high mountains of Haleakala, Mauna Loa, and Mauna Kea, the zones of highest rainfall lie on the windward flanks at elevations of 2,000 to 4,000 feet.

Generally, rainfall is heavier during the winter months. In Kona, Hawaii, however, the summer months are wetter.

Annual variability can be great. At Hilo, Hawaii, the lowest annual total has been 72 inches, and the highest, 207 inches. In Honolulu, annual totals range from 10 inches to 46 inches; at Mana, Kauai, they range from 5 to 48 inches. Monthly totals are even more variable. Some extreme variations are: January rainfall at Hilo, less than 0.2 inch to more than 50 inches; in Honolulu, 0.12 inch to 18 inches; and August rainfall at Hilo, 2 to 28 inches; in Honolulu, 0.2 to 4 inches.

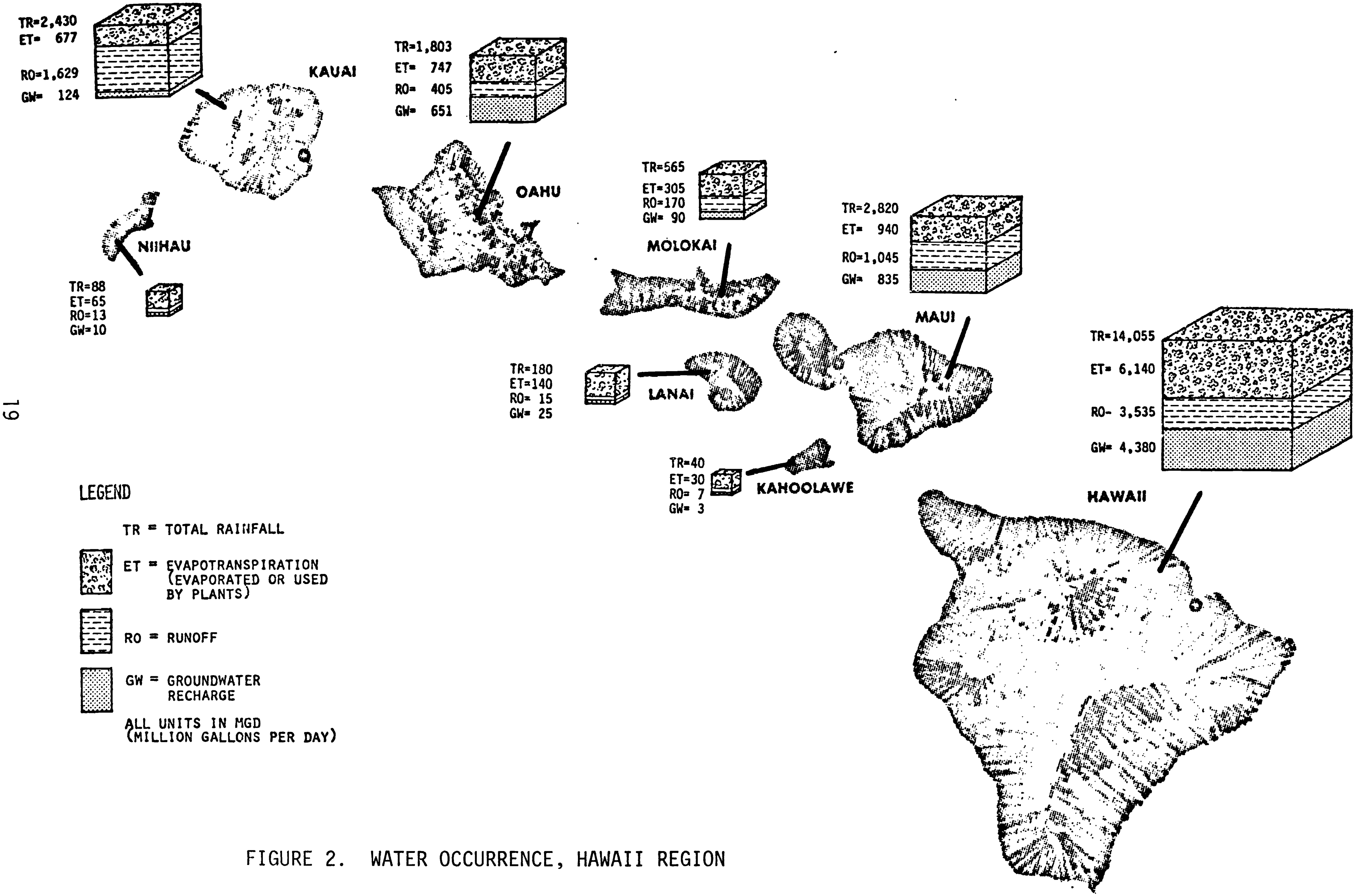


FIGURE 2. WATER OCCURRENCE, HAWAII REGION

Surface Water

Areal Distribution

The availability of surface water in any area within the Region depends primarily upon the amount of rain that falls upon the area. Thus, in general, the quantities of surface water in different areas vary in accordance with the quantities of rainfall as shown on the isohyetal maps in the section on Climatology. Where rainfall is plentiful and well distributed during the year, as in the mountainous areas of each of the major islands, streams are usually perennial and abundant. Where rainfall is light, especially in the southwestern end of each of the major islands and on Kahoolawe, Lanai, and Niihau, streams are ephemeral, flowing only at infrequent times of extremely heavy storm rains.

The availability of surface water in any area is also influenced by the geology of the area. There is little streamflow in some areas of abundant rainfall, because the rain falls upon highly permeable rocks. Most of the rain sinks rapidly into the ground to either reappear eventually at lower elevations as springs draining dike-held bodies or perched-water bodies, or become part of the basal-water body that underlies each island. Springs, either from perched-water bodies or from the basal-water body, maintain streamflow in some areas of lesser rainfall. Some streams are perennial throughout their length while others are perennial in their upper reaches but ephemeral in their lower reaches because their streambeds are extremely porous. The effects of geology is apparent when the characteristics of streamflow are analyzed. Streams fed by ground water (springs or seeps) usually have sustained flows during the drier seasons of each year; others often go dry.

Perennial stream discharges into the ocean occur in sections of each of the major islands as indicated below:

Hawaii:	Hamakua Coast
	North Kohala Coast
Maui:	Palikea to Wailua
	Makapipi to Huelo
	Waihee to Honokohau
Molokai:	Waialua to Waikolu
Oahu:	Waikele to Halawa, Kalihi to Palolo
	Waimanalo to Punaluu, Anahulu and Kiikii
Kauai:	All parts except the sector west of Waimea Canyon.

<u>Variation of Streamflow with Time</u>

In Hawaii, the availability of surface water, at any time, depends primarily upon the amount of rain that falls during that time. This is so because the streams are short and steep. Except for the portion of flow derived from ground water, and, in a few places, from outflow from swampy terrain, streamflow responds directly to rainfall.

Temporal variations of surface water, therefore, correspond closely to variations of rainfall. This relationship is somewhat moderated by watershed factors.

Ground Water

Effects of Geology and Rainfall on Occurrence and Amount of Ground Water

Most of the rain falls on volcanic terrane in mountainous areas. The highest rainfall occurs along the lower windward slopes of the very high mountains on the islands of Hawaii and Maui and at or near the summits of the lower mountains of Kauai, Oahu, and West Maui. A part of the rainfall infiltrates and provides recharge to underlying ground-water bodies. The quantity of recharge to ground water is dependent on the availability of rainfall and the ability of the surface rocks to absorb the rainfall. Except for areas where sugarcane is heavily irrigated, the areas of greatest recharge to ground water generally coincides with the areas of greatest rainfall.

The ability of surface rocks to absorb the rainfall for deep infiltration is generally correlative with their water-bearing property described in table 2. The pervious nature of surface volcanic rocks are commonly reduced considerably by deep weathering. Hence, the surface rocks of younger islands, such as Hawaii, are generally more pervious than those of an older island, such as Kauai, even though the rock types and their modes of eruption may be similar.

Ground water occurs as basal water, as dike-impounded water, and as perched water.

Basal Water

Ground water in dike-free rocks outside the eruptive zones occurs as basal water, the fresher part of which forms a lens-shaped body floating on saline ground water, whose salinity approaches that of seawater. Where permeable rocks are overlain by caprock material in coastal-plain areas, basal-water bodies occur under artesian conditions and are commonly several hundred feet thick. Where caprock material is absent, basal-water bodies are thin, are generally brackish near the coast, and occur under water-table conditions. Basal-water bodies provide most of the ground water developed in the Hawaiian Islands.

Dike-Impounded Water

Dike-impounded ground-water bodies occur mostly in dike-intruded lava flows and occasionally in other rock types within the eruptive zones. Occurrence of these bodies in calcareous sediments is not known in the Hawaiian Islands. Because they occur and are easily developed at the higher altitudes, they provide important sources for gravity-flow domestic and irrigation-water systems. The natural discharge from dike-impounded water bodies provides the base flow of many large perennial streams.

Perched Water

Ground-water bodies perched above dike-impounded and basal-water bodies are common in the Region. Most, however, are small and quickly drained after rains. The perching members are weathered ash, weathered lava surfaces, soil, or any poorly permeable horizon interbedded in lava flows, cinders, calcareous sediments, or other permeable rocks. Many perched water bodies have been developed by tunneling and provide important sources of water, especially at high altitudes in isolated places.

A diagrammatic cross section showing occurrence and development of ground water in an idealized Hawaiian volcanic dome is shown (fig. 3).

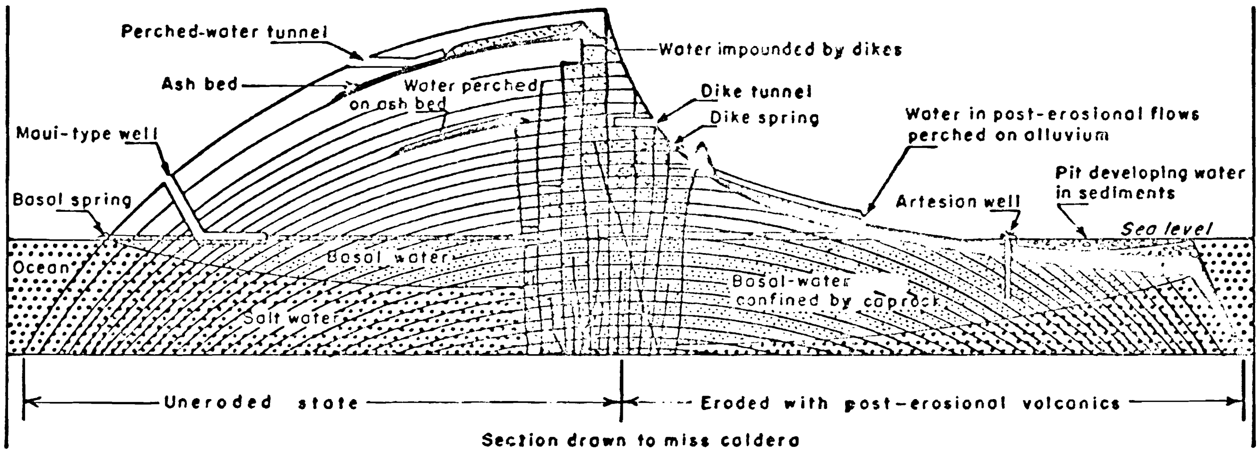


FIGURE 3. OCCURRENCE AND DEVELOPMENT OF GROUND WATER IN AN IDEALIZED HAWAIIAN VOLCANIC DOME (AFTER COX,1954)

Quality of Water

Rainfall is the source of almost all fresh water in Hawaii. The quality of rainwater is, therefore, the origin of surface- and ground-water quality.

Unlike in areas of conterminous United States, Hawaii has no major river basins. Hawaiian streams are relatively short and flashy and do not assimilate excessive minerals nor pollutants. Water-quality problems are quickly transmitted to coastal-receiving waters.

Ground water is the principal source of potable water in Hawaii. Factors affecting the quality of ground water are: (1) over-development, which may lead to salt-water encroachment; (2) agricultural and industrial uses and discharges, which could deteriorate present and potential water supplies; and (3) indiscriminate surface and underground waste disposal, which could introduce potential contaminants. Protecting the high quality of Hawaii's ground waters should be a major effort for all water-management programs.

Surface-Water Quality

This section describes the general characteristics of the surface-water quality. Discussions are arbitrarily limited to perennial flows not affected by tidal or seawater intrusion. Conclusions are based on available data obtained from the files of the U.S. Geological Survey, Hawaii State Department of Health, State Division of Fish and Game, the University of Hawaii, Honolulu Board of Water Supply, and the military.

The U.S. Geological Survey, in cooperation with the Division of Water and Land Development, State Department of Land and Natural Resources, began collecting surface-water samples for mineral analysis in 1970. Data are being collected during high- and low-flow periods to help define the baseline chemical quality of surface-water streams.

The Hawaii State Department of Health (DOH) has broad responsibility over the health and sanitary conditions of Hawaii's waters. It (DOH) monitors the usability of the waters from the bacteriological, as well as the chemical, standpoint. Coliform data are plentiful for potable water supplies and coastal water bodies, but are scarce for fresh-water streams. Some other data have been collected during special-purpose investigations and research projects.

Chemical Quality

The chemical quality of stream waters is excellent. It generally follows a pattern of dilution brought about by rainfall. No significant levels of pesticide or toxic chemicals have been detected.

Dissolved-solids content of stream waters ranges from less than 50 mg/l (milligrams per litre) at headwaters to greater than 200 mg/l near the stream mouth. The increase is due primarily to ground-water discharge, and usually occurs at lower reaches. Irrigation-return flows and urban activities also add to the dissolved-solids content.

Hardness of water can be attributed to the presence of dissolved calcium and magnesium. Water is commonly classified as hard or soft. It is considered soft when the hardness value is less than 60 mg/l expressed as calcium carbonate. Most surface water in Hawaii is soft, exceptions being for streams fed principally by basal ground water or irrigation-return flows.

Nitrogen and phosphorus are important nutrients in environmental considerations. Undesirable aquatic growths can result in water having high nutrient content. Hawaii's Water-Quality Standard has not established a limit for nitrogen in fresh-water streams; the limit for phosphorus is 0.20 mg/l. Nutrient standards for Class A coastal waters, which receive most perennial streamflows, are more stringent. The nitrogen limit is 0.15 mg/l and the phosphorus limit is 0.025 mg/l.

Surface-water bodies that receive sewage effluents, industrial wastes, and urban or agricultural runoffs generally contain significant nutrient load. Waikele Stream at Waipahu averaged 2.2 mg/l of nitrogen and 1.2 mg/l of phosphorus during 1973. Reports of research projects from the University of Hawaii show that Kalihi Stream, Kapalama Stream, Manoa Stream, and Kaneohe Stream all failed to meet Class A water-quality standards. Concentrations increase during wet-weather conditions.

Physical Quality

The physical quality of stream water is characterized by its "flashy" conditions. High turbidity and suspended-sediment concentrations occur during periods of heavy precipitation. Storm durations are short, and most streams revert to base flow and clear conditions within a few hours. During base flow, stream turbidity seldom exceeds 5 JTU (Jackson Turbidity Units); but, during storm runoffs, readings greater than 100 JTU are common.

Surface waters in different areas contain different amounts of color. The color bodies are predominantly organic in origin. They often taste peaty, and the water is esthetically unsuitable for domestic use. Streams in the south Kohala area on the island of Hawaii have reported values of 22 to 320 color units.

Stream temperatures do not vary significantly. They generally fluctuate with ambient conditions. Recorded temperatures have ranged from 14 to 30 degrees centigrade. Temperatures are higher in concrete-lined channels and are highest at base-flow conditions.

Biological Quality

Bacteriological data for surface streams are scanty. There has been no systematic monitoring of bacterial densities, and meaningful interpretation cannot be made. But, research data and grab-sample analyses from Oahu streams generally indicate poor bacterial quality. Total coliform counts often exceed 1,000 colonies per millilitre of water. The counts are generally higher during wet-weather conditions. Both total- and fecal-coliform densities on many Oahu streams exceed Hawaii's Water-Quality Standard. Treatment is necessary to lower the bacterial densities for domestic uses.

Limnological surveys on 153 streams have been completed by State Division of Fish and Game to assess the potentials for developing public fishing areas. Preliminary findings indicate good development potentials for 111 streams; poor for 21 streams; little for the other 21.

Suitability for Use

The surface waters of Hawaii are chemically suitable for most uses. All the streams for which data are available are suitable for domestic and municipal use, but treatment may be required to remove bacterial and organic contaminants. In some areas, removal of color and turbidity may also be required to meet recommended standards.

The surface water has low salinity, and is suitable for irrigation. Water with high salt content, found at tidal reaches, should not be used for sensitive crops.

Ground-Water Quality

In general, good quality water is available in Hawaii's major basal-, dike-, and perched-water bodies. All ground waters developed for public and domestic purposes are chemically suitable for use without treatment. Concentrations of all constituents are within the limits of drinking water standards recommended by the U.S. Public Health Service. No significant levels of organic contaminants, pesticides, or toxic chemicals have been detected.

Waters containing more than 500 mg/l of dissolved solids are plentiful. They are not currently considered suitable for domestic use, but may be important for future needs. These fresh-to-brackish water bodies are located in permeable sediment deposits of coastal plains and valley-fill areas. They are presently used as sources by agriculture and industry, and are highly susceptible to contamination.

Geology and hydrology are the two main controls on the chemical quality of ground water. In an island environment, seawater can freely penetrate basal aquifers, unless they are capped by low-permeability material, or unless fresh-water head is sufficient to "block-out" the seawater intrusion.

Man's activities oftentimes change the geohydrologic environment, and alter the chemical characteristics of ground water. Overpumpage can cause upconing of saline water. Water fertilizers and other soluble chemicals applied on the surface can be leached into the aquifers. Indiscriminate subsurface waste disposal could also change the quality of Hawaii's ground water.

Chemical quality differs considerably among sources of ground water. Generally, dissolved-solids concentrations are higher in basal waters than in perched or dike-impounded waters. Silicate concentrations are lowest in perched waters. Hardness of ground water ranges from less than 60 mg/l to more than 1,000 mg/l.

Higher than normal nitrate and sulfate concentrations are good indications that irrigation water may be reaching basal aquifers. The reported concentrations, however, are not yet at the level of public-health hazard.

The physical quality of ground water is excellent. The water is usually free of color and contains little or no turbidity. The pH values range between 6.8 and 8.4 units. No offensive taste or odor has been found in potable ground-water sources.

Incidences of bacterial contamination in ground waters are low. Excessive coliform counts when detected, have been generally traced to local contamination, bad sampling techniques, or faulty distribution systems.

Hawaii Island Subregion

The island of Hawaii was built by lavas, which emanated from five volcanoes, namely Mauna Kea, Mauna Loa, Hualalai, Kohala, and Kilauea. The lavas of Mauna Loa interfinger with the latest lavas of the Kohala volcano.

The bulk of each volcanic dome is composed of permeable thin-bedded basaltic lava flows. A veneer of andesitic lavas covers much of Mauna Kea, and one of andesite and trachyte covers part of the Kohala Mountains. The andesitic and trachytic flows are mostly thick-bedded and are poorly permeable. Numerous dikes have intruded lava flows in the rift zones, but dikes are exposed only in deeply eroded valleys in the eastern slope of the Kohala Mountains. They form almost impermeable vertical barriers, which cut across lava flows and oftentimes impound large quantities of ground water. Volcanic-ash deposits, several feet thick in places, crop out in about 450 square miles of the northern, northeastern, and southeastern parts of the island. Most of the ash has been buried by later lava flows. The buried ash deposits, intercalated in permeable lava flows, act as perching members for important high-altitude perched-water bodies in much of the northeastern and southeastern parts of the island.

The limited number of perennial streams indicate the highly pervious nature of much of the surface rocks. Some streams flow perennially in their wet upper reaches but lose their water to the ground well before reaching the sea.

There is little evidence of extensive coastal-plain sedimentation and of deep erosion, except in the northeastern slopes of Kohala Mountains and Mauna Kea. Sedimentary materials, as a result, are sparse and scattered. They include alluvium, talus, dune and beach deposits, and glacial deposits on Mauna Kea. They are not important hydrologically, owing to their sparsity.

A geologic map of the island is shown in figure 4 and the stratigraphic sequence of the rocks are shown in the following table 3.

In general, ground-water conditions are better along coastal areas exposed to the trade winds. Although the recharge to ground water from rainfall is large even in the drier areas, development of ground water, especially that of basal water, is difficult and costly in many coastal areas because of mixing far inland.

A rough accounting of the disposition of rainfall on the island is shown in figure 5 and in table 4. Water developed for irrigation is combined with evapotranspiration unless exported out of or imported into an area, and is not accounted for separately.

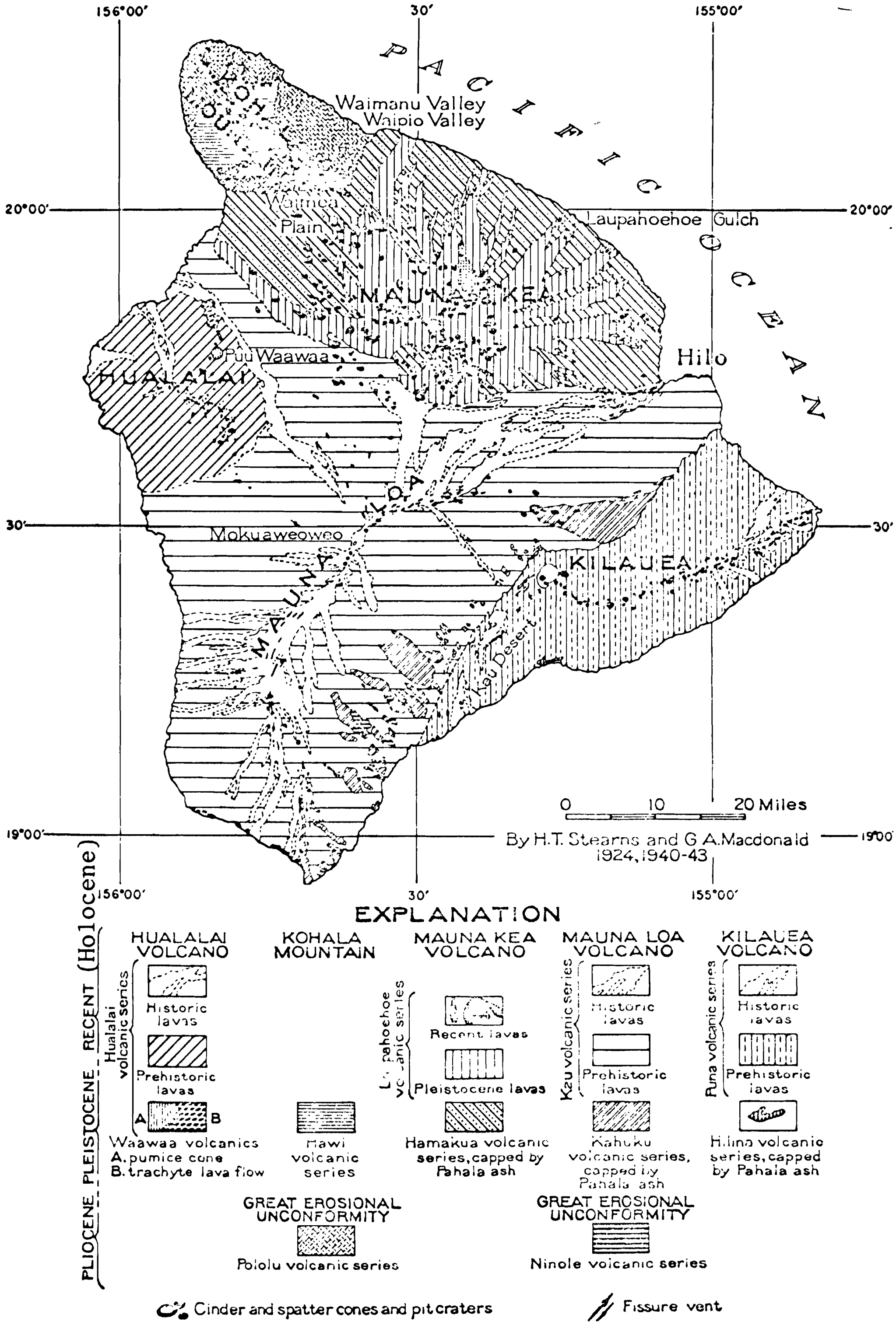


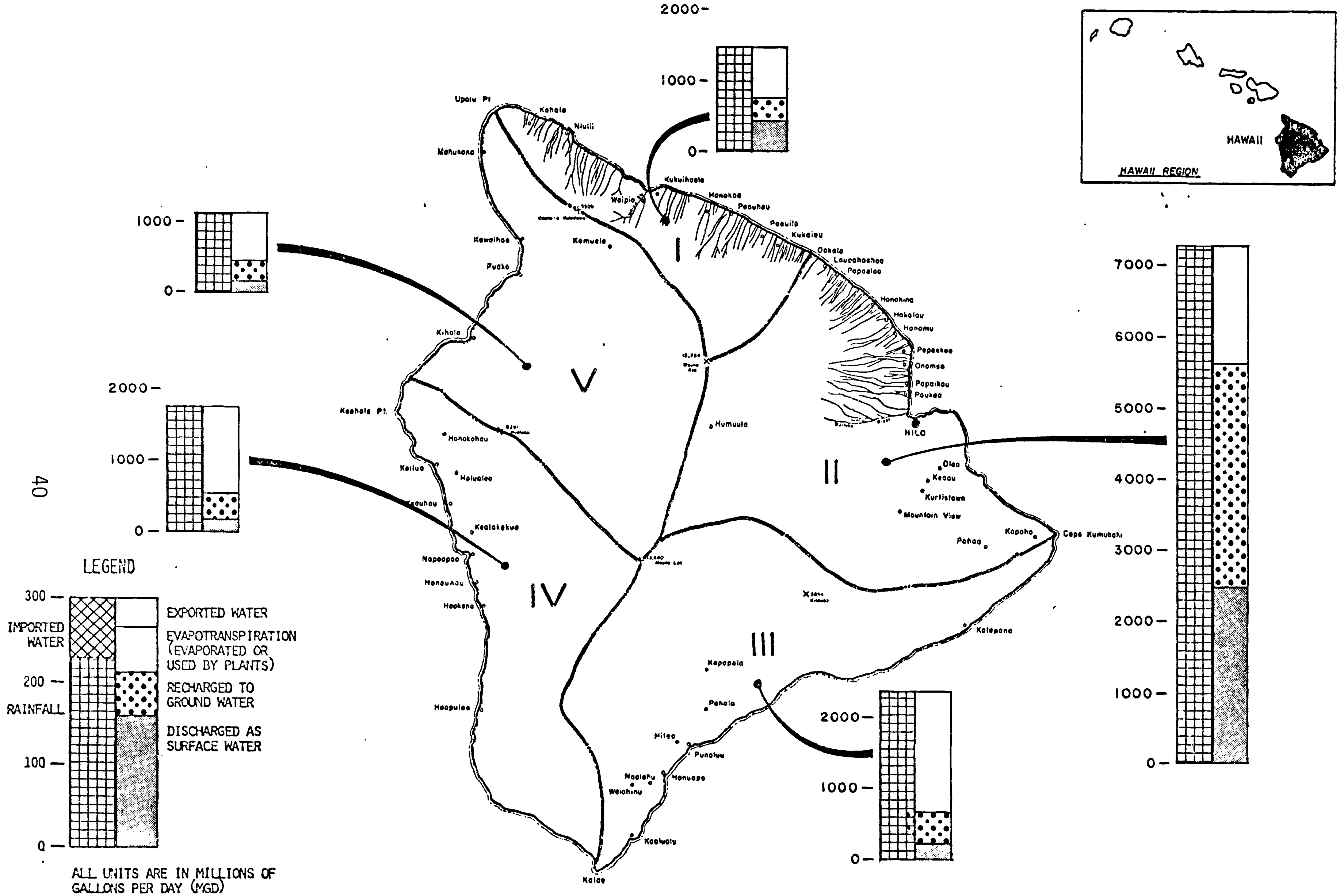
Figure 4. —Geologic map of the island of Hawaii. Faults and dikes omitted.

TABLE 3

Stratigraphic Rock Units in the Island of Hawaii

(The volcanic rocks of Mauna Loa, Mauna Kea, and Hualalai, those of Mauna Kea and Kohala, and those of Mauna Loa and Kilauea interfinger)

Age	Hualalai	Kohala Mountain	Mauna Loa	Kilauea	Mauna Kea
Historic	Historic member of the Hualalai volcanic series (1800–01)	Unconsolidated alluvium, dunes and landslides	Historic member of volcanic series (1832–1950) / Mud flow of 1868	Historic member of the Puna volcanic series (1790–1965)	Ribbons of gravel and small alluvial fans
Recent (Holocene)	Prehistoric member of the Hualalai volcanic series		Dunes / Prehistoric member of the Kau volcanic series	Dunes / Prehistoric member of the Puna volcanic series	Upper member of the Laupahoehoe volcanic series
Late Pleistocene	Pahala ash (exposed on Waawaa volcanics only)	Fluvial conglomerates / Pahala ash (not differentiated)	Pahala ash	Pahala ash	Glacial debris and fluvial conglomerates / Lower member of the Laupahoehoe volcanic series / Local erosional unconformity / Pahala ash
Early and middle Pleistocene	Waawaa volcanics and lower unexposed part of Hualalai volcanic series	Fluvial conglomerates / Hawi volcanic series	Kahuku volcanic series	Hilina volcanic series	Hamakua volcanic series
		Great erosional unconformity	Great erosional unconformity		
Early Pleistocene		Pololu volcanic series	Ninole volcanic series		



SUBREGION I
ISLAND OF HAWAII

FIGURE 5. WATER OCCURRENCE

Table 4. Disposition of rainfall

Island of Hawaii
(Units in mgd)

Area	Rainfall	Evapotranspiration	Runoff	Ground-water flux
I	1,430	695	430	305
II	7,335	1,730	2,510	3,095
III	2,340	1,705	235	400
IV	1,790	1,265	180	345
V	1,160	745	180	235

The quality of surface water on the island of Hawaii is excellent. Its characteristics are similar to those of the rainwater, which feeds the island streams.

The mineral content of stream waters is low. Average dissolved-solids concentration seldom exceeds 50 mg/l; the highest reported value is 88 mg/l from Pohakupuka Stream near Papaaloa.

Bicarbonate is the major anion dissolved in surface water. There is no dominant cation. Calcium, magnesium, and sodium all appear in about equal percentages of ionic composition. Chloride has ranged from 2.0 mg/l to 8.9 mg/l for all samples analyzed by the U.S. Geological Survey.

Surface waters are classified as soft. Hardness values did not exceed 46 mg/l. Figures 6 through 9 give the ranges and average concentrations of dissolved solids, hardness, chloride, and silica for selected streams on the island of Hawaii.

Nutrient contents are low. Nitrate-nitrogen seldom exceeds 0.1 mg/l, and phosphate-phosphorus ranged from 0.00 to 0.05 mg/l.

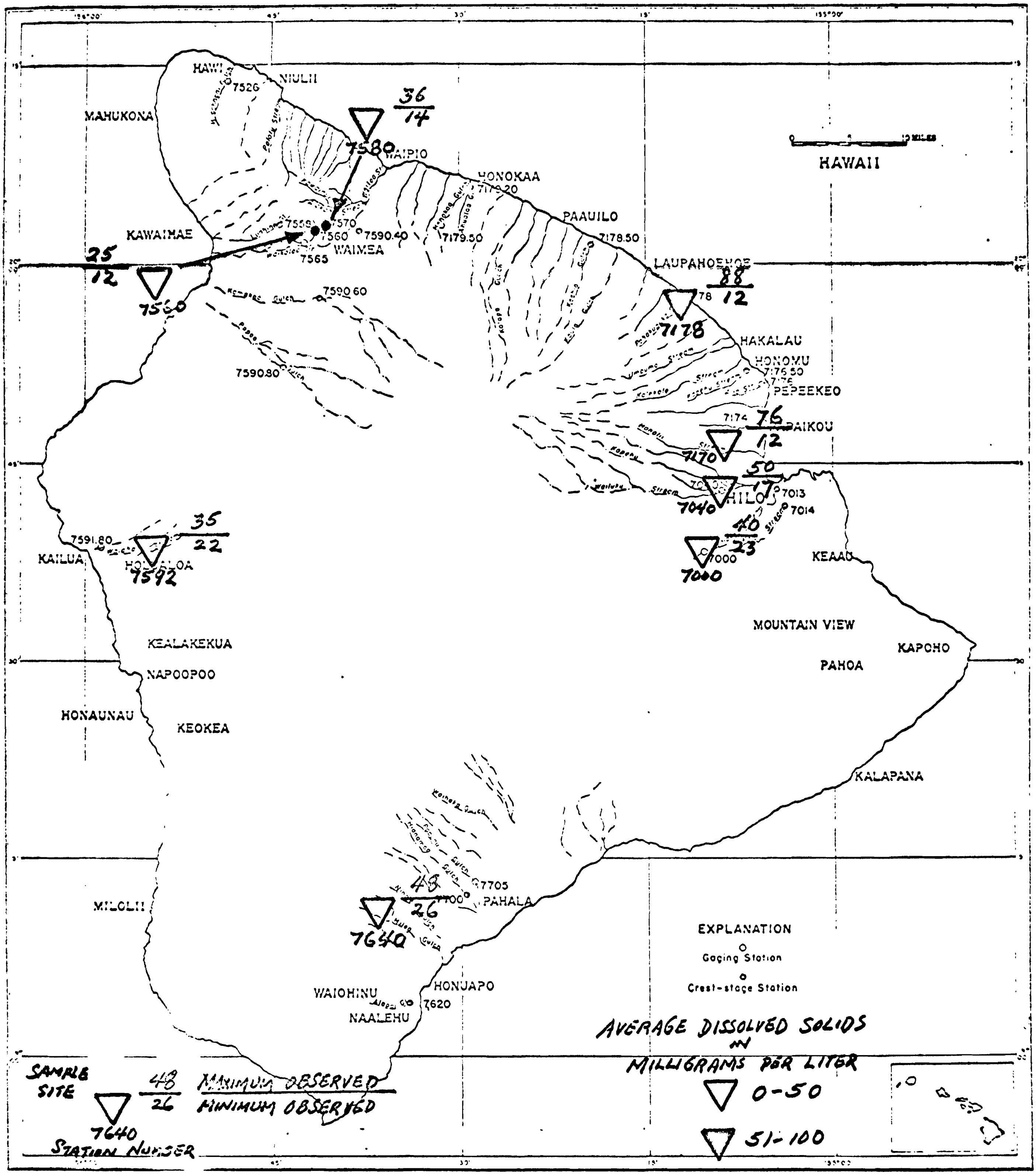


FIGURE 6. RANGE AND AVERAGE DISSOLVED-SOLIDS CONCENTRATION IN SELECTED STREAMS.

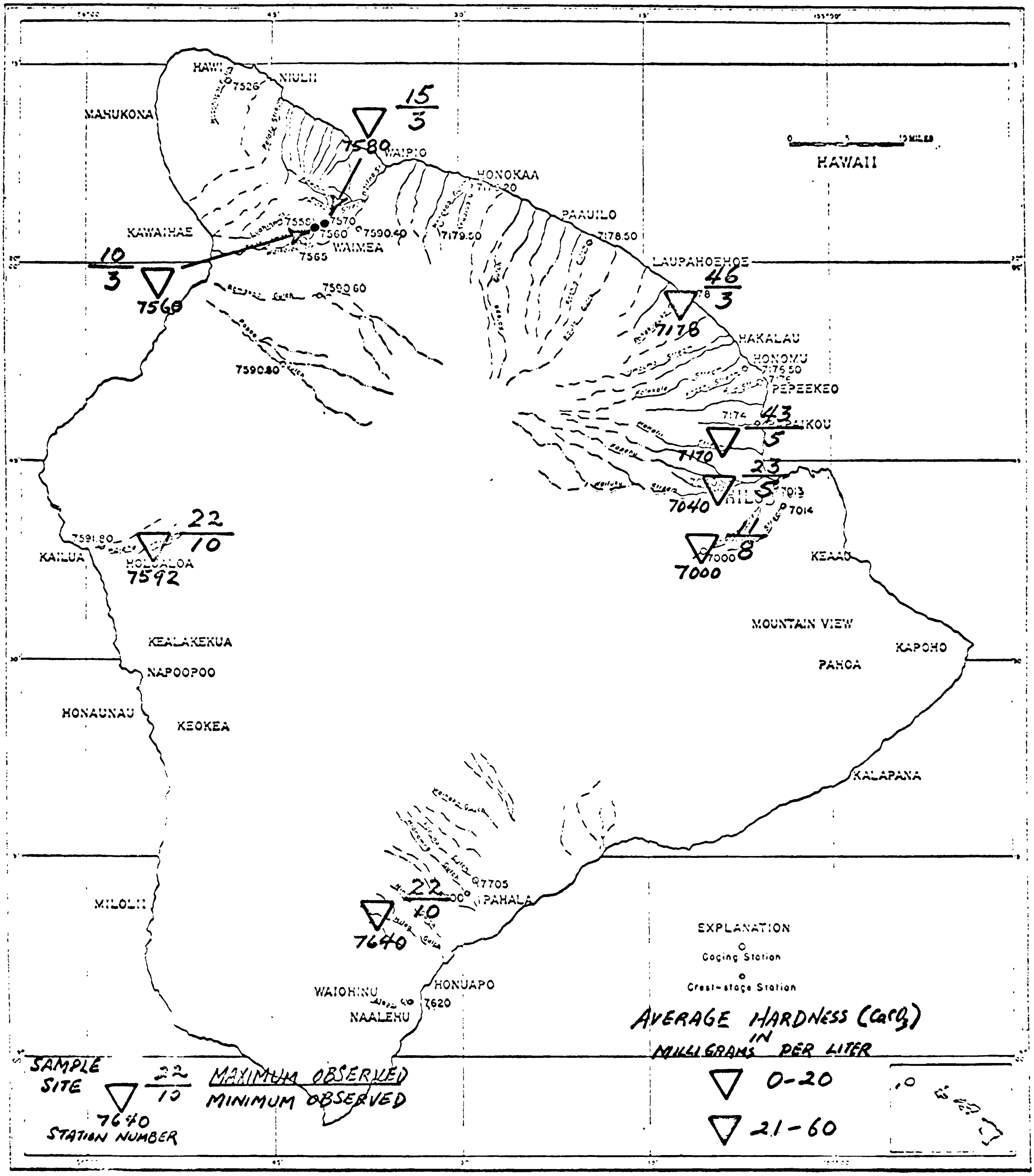


FIGURE 7. RANGE AND AVERAGE HARDNESS CONCENTRATION IN SELECTED STREAMS.

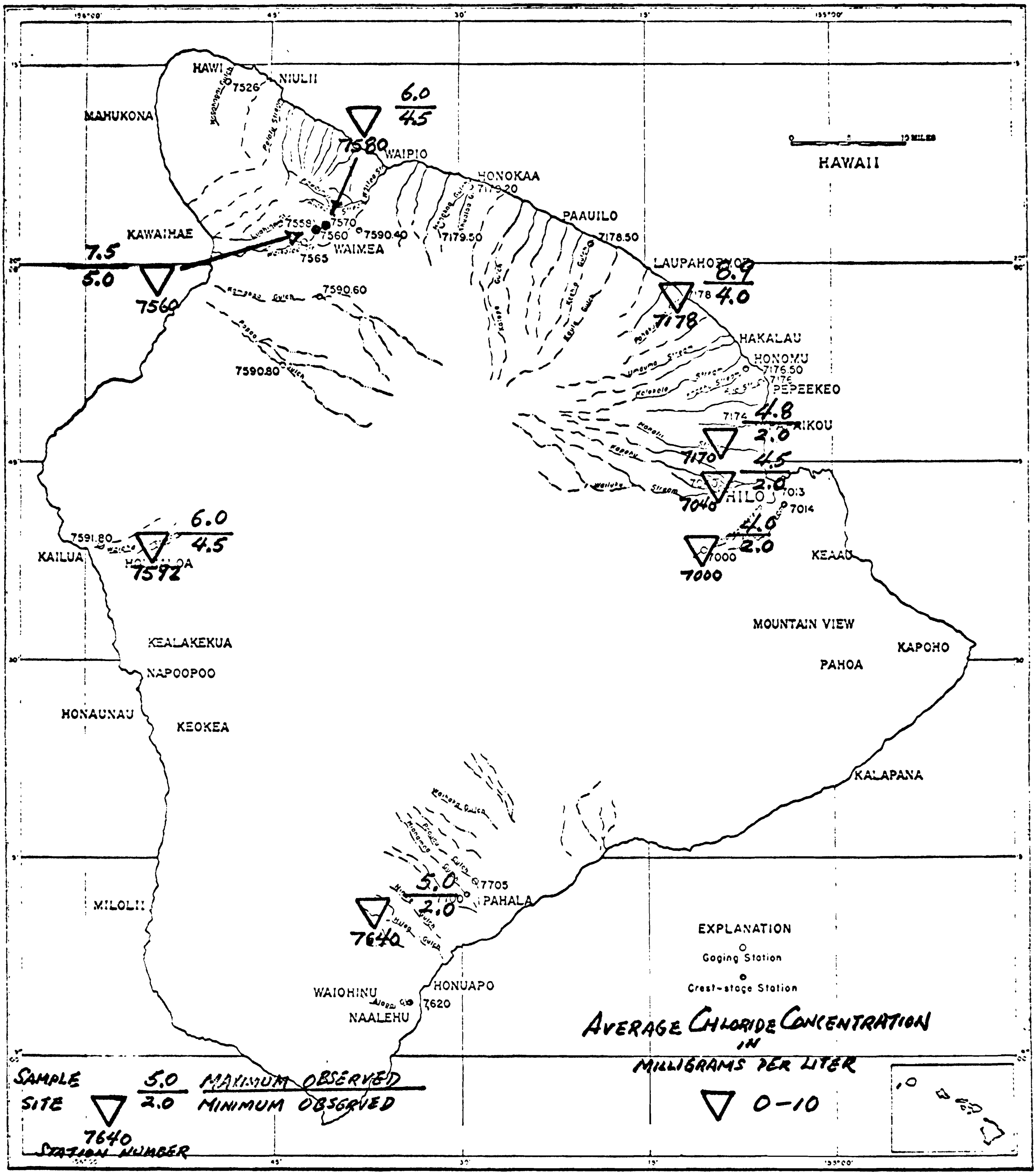


FIGURE 8. RANGE AND AVERAGE CHLORIDE CONCENTRATION IN SELECTED STREAMS.

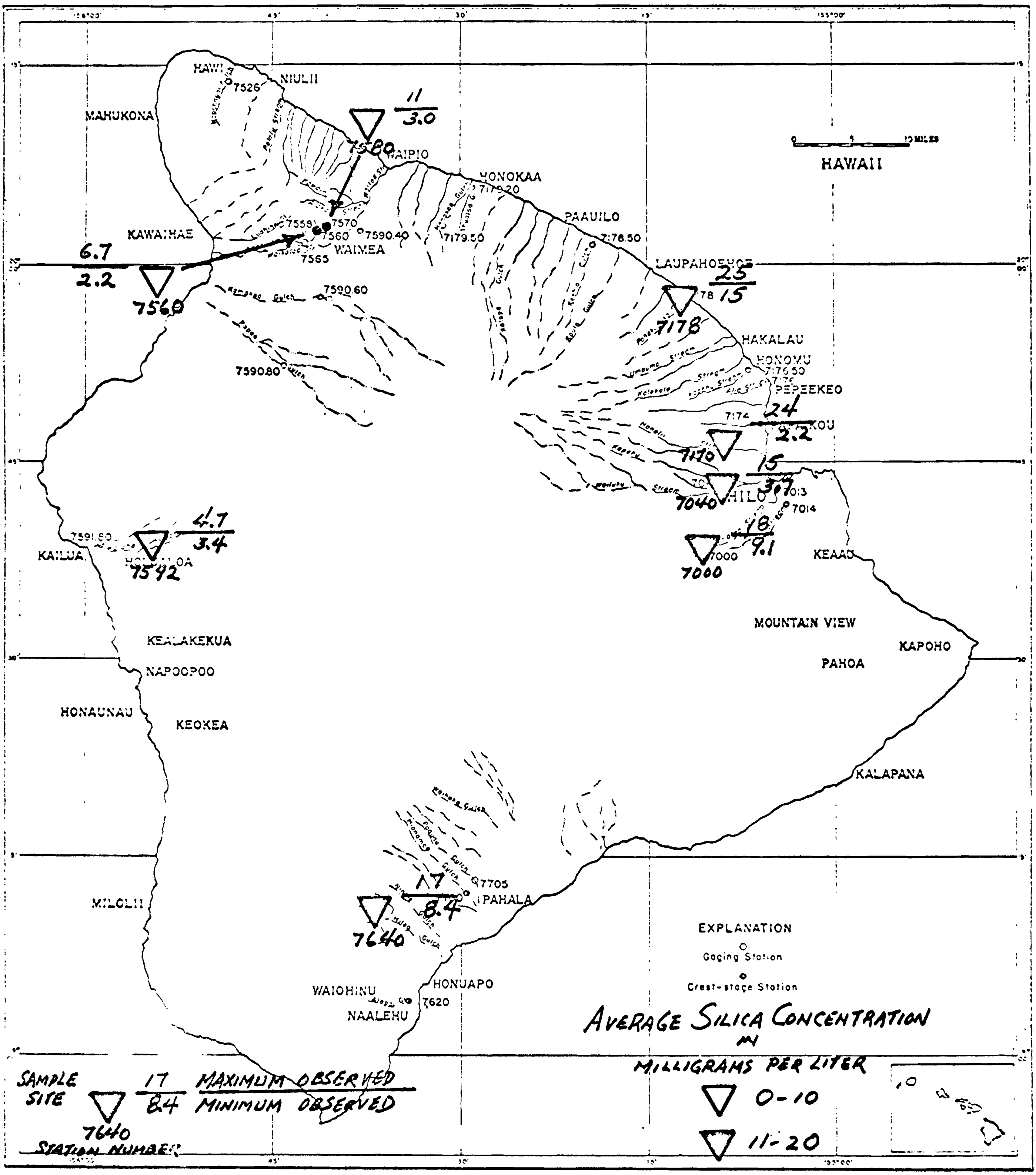


FIGURE 9. RANGE AND AVERAGE SILICA CONCENTRATION IN SELECTED STREAMS.

The high-color content of the waters draining the south Kohala streams is attributed to organic compounds leached from boggy swampland. The organics impart a peaty taste, and the water is esthetically unpleasant to drink. Removal or reduction of color is required to make the water suitable for domestic use. Waikaloa Stream water has color ranging from 22 to 320 platinum units; it is slightly acid, with pH values ranging from 5.8 to 7.9 and average 6.9 units. High-color content is also reported for waters from Alakai and Kohakohau Streams.

Limnological data indicate that most perennial streams on Hawaii have excellent potential for future development as public fishing areas. They appear to be well suited for stocking of game fish.

Total-coliform data collected from Honolii Stream near Papaikou indicate that high-level waters have good bacteriological quality. Monthly grab-samples analyzed during 1970-73 seldom contained more than 200 total-coliform colonies per millilitre of water. Data are not available, but fecal-coliform content is also expected to be low because the watershed area has not been greatly affected by activities of man or animals.

Pesticide and radiochemical determinations on water samples from Honolii Stream showed no significant concentrations.

Ground-water quality varies considerably on the island of Hawaii. Most of the ground water developed is from permeable volcanic aquifers, which are recharged by rainwater or streamflows infiltrating the land surface, and chemical characteristics of the water range from stream-like composition in aquifers to near seawater composition near the coast. Waters from inland wells tapping the uppermost layer of the fresh-water lens show dissolved-solids contents of less than 150 mg/l. The chloride contents from these wells are less than 20 mg/l. Coastal ground waters, generally not suitable for domestic use, are predominantly of the sodium-chloride type.

Perched waters in the north Kohala Mountains have excellent quality. The water has low dissolved solids, and is a mixture of sodium, calcium, magnesium, and bicarbonate. It has been developed and used for domestic and irrigation supplies without treatment.

Recent volcanic activities appear to have affected some ground water on the island of Hawaii. High bicarbonate and fluoride concentrations have been noted (Swain, 1973). Water samples from a well within Kapoho cone showed bicarbonate concentrations ranging from 283 mg/l to 976 mg/l. Another well in the Hualalai Volcanic Series had a bicarbonate range of 260 mg/l to 439 mg/l. The fluoride concentration of this well ranged from 2 to 2.2 mg/l, significantly higher than concentrations found in most Hawaiian waters, which rarely exceed 0.4 mg/l. Swain attributes the high concentrations to volcanic gases entering the water source. High silica and potassium anomalies may also be attributed to volcanic or geothermal activities, but data are not sufficient to make any definite conclusions at this time.

Area I

Geology

The Kohala Mountains consist of a shield volcano built around two rift zones that trend northwestward and southeastward from the summit region. The bulk of the mountain is composed of thin-bedded basaltic lava flows of the Pololu Volcanic Series, the oldest rock of the Kohala Mountains. The Pololu rocks are cut by numerous dikes in the rift zones. The formation of the Pololu Volcanic Series was apparently followed by a period of long quiescence, during which time valleys were deeply incised and subsequently filled with debris. Major volcanism resumed with eruption of the Hawi Volcanic Series, which presently forms a thin, discontinuous cap of andesite and trachyte on the mountain and separated from the underlying Pololu rocks by erosional unconformity and a layer of soil.

The rocks of the Mauna Kea section of this area are mostly of the Hamakua Volcanic Series consisting of basaltic and andesitic lava flows. Pahala Ash, consisting of discontinuous beds of volcanic glass and pumice, overlies these rocks. The youngest rocks are those of the Laupahoehoe Volcanic Series, with a lower member of andesitic and basaltic lava flows and an upper member of cinder cones and some andesitic flows.

Sedimentary deposits composed of dune sand and consolidated alluvium occur in some coastal areas and in the larger valleys.

The principal aquifer consists of thin-bedded flows of the Pololu Volcanic Series. The flows are highly permeable and freely yield water to wells and to high-level tunnels in the rift zones. Soil at the top of the Pololu rocks gives rise to many perched springs. The rocks of the Hawi Volcanic Series consists of mostly dense flows and generally are poor aquifers. Weathered Pahala Ash is relatively impermeable, and where interbedded with lava, it perches small quantities of water in wet areas. The areal distribution of rocks in the subarea is shown in figure 10. The sequence of rocks and their water-bearing properties are given in the following tables.

Rainfall

Most of the rain results from cooling of warm moist tradewind air, as it is orographically lifted. The heaviest rainfall on the Kohala Mountains, about 200 inches per year, occurs on the windward side of the summit crest. On the basis of the rainfall map shown on figure 11, rainfall was computed to average 1,430 mgd. About 640 mgd falls on the slopes between Ookala and Kukuihaele, 650 mgd falls between Kukuihaele and Niulii, and about 140 mgd falls between Niulii and Upolu Point.

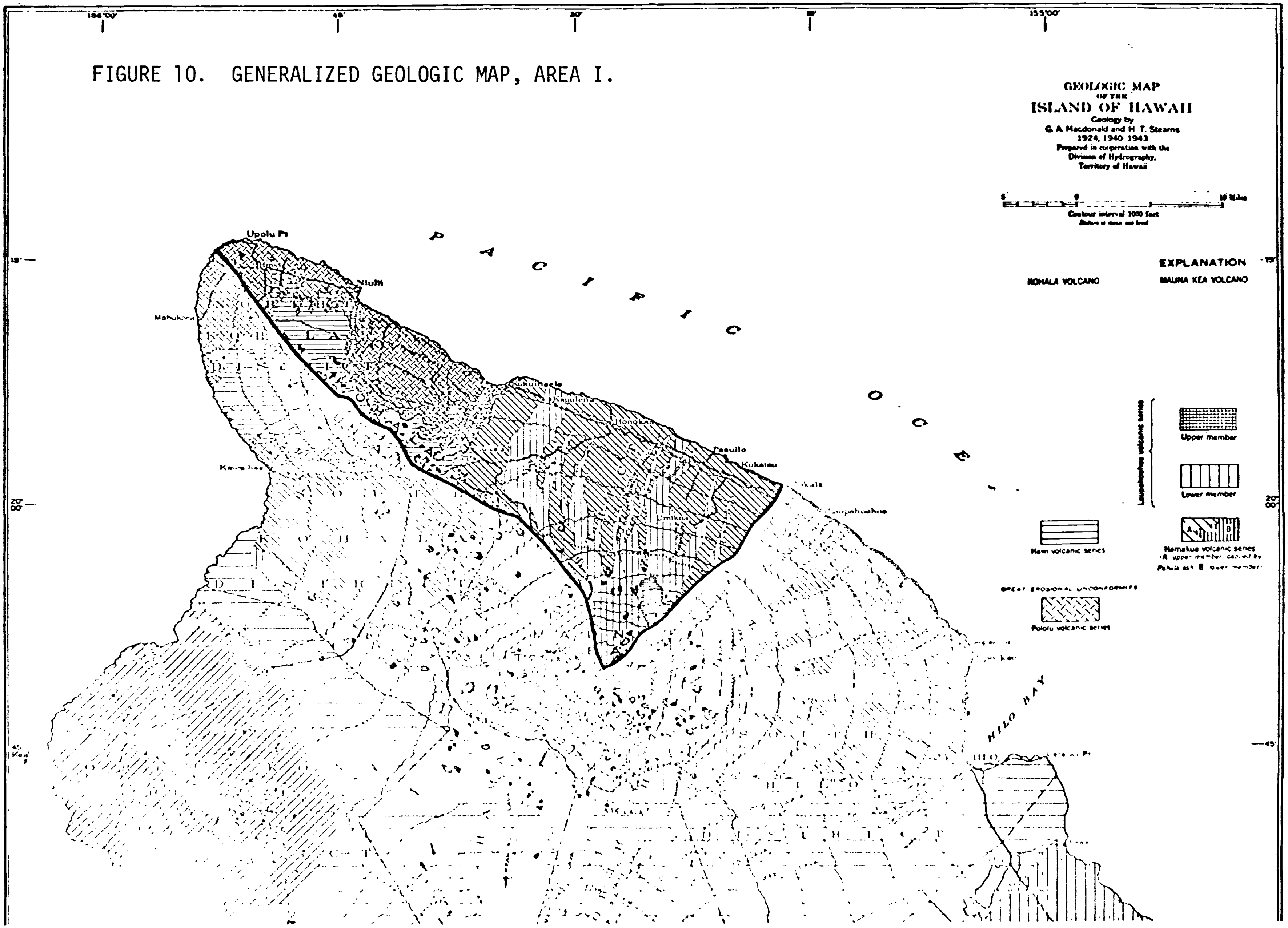


FIGURE 10. GENERALIZED GEOLOGIC MAP, AREA I.

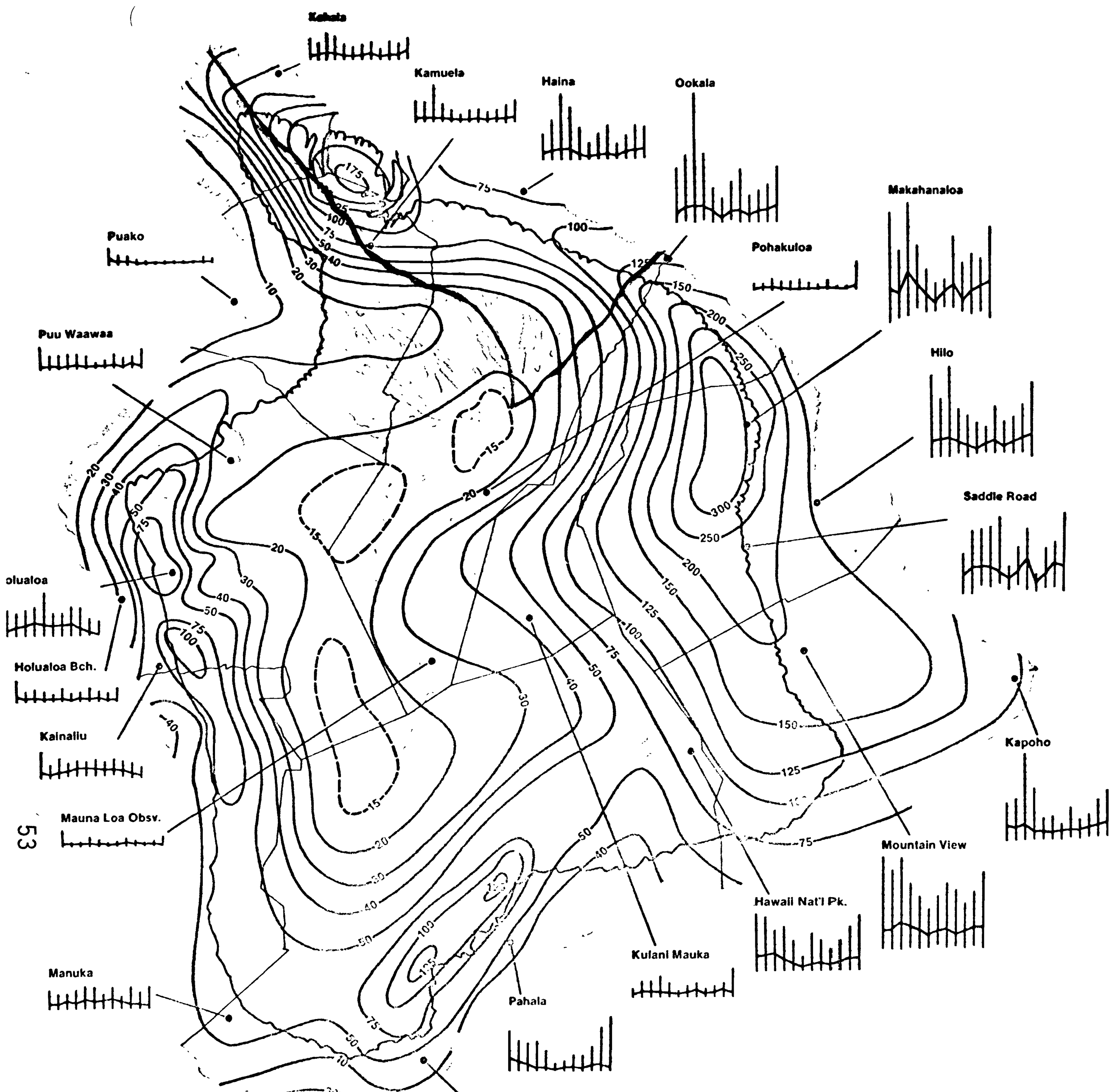
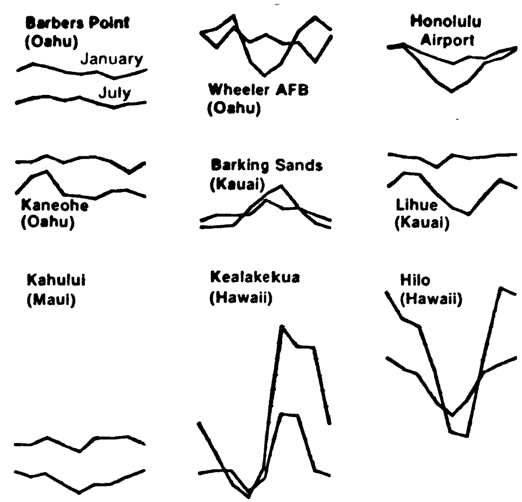


FIGURE 11. AREAL DISTRIBUTION OF RAINFALL, AREA I.

RAINFALL FREQUENCY BY HOUR OF DAY

Three Hour Intervals Centered at Hour Shown



The diurnal variation in rainfall frequency differs from place to place in Hawaii, since it represents a complex interplay between terrain and wind—both the large-scale flow and the local air movements produced by day-to-night temperature contrasts between land and sea. In places well exposed to the trade winds, showers are usually more frequent during the night and early morning (for example, Lihue in July), reflecting conditions over the open sea or an interaction between the trades and nocturnal offshore land breezes. In contrast, areas sheltered from the trade winds (like Kealakekua, in Hawaii Island's Kona district) tend to have their rainfall maximums in late afternoon and evening, from showers that form within sea breezes which move onshore and upslope during the day.

Although Hawaii has considerably more gages than almost any other area of comparable size, the rainfall of its inaccessible or uninhabited regions remains largely conjectural. Nor is nearly enough known about the effects of smaller terrain features or about contrasts in rainfall between adjoining ridges and valleys.

Table 5. Stratigraphic Section of Kohala Mountain
(After Stearns and Macdonald, 1946, and Macdonald and Davis, 1956)

Major geologic unit	Rock assemblages	General character	Water-bearing properties
Recent (Holocene) sedimentary rocks	Unconsolidated dunes, alluvium, and landslide deposits	Dunes of black basaltic sand; boulder deposits in streambeds and silt and sand underlying broad valley floors; landslide deposits contain blocks of volcanic rock in earthy matrix.	Dunes are permeable but carry brackish water; alluvium generally poorly permeable; landslide deposits carry little water.
Pleistocene sedimentary rocks	Consolidated alluvium, landslide deposits, and marine calcareous conglomerate	Boulder conglomerate forming terraces in valleys; landslide deposits of blocks of volcanic rock cemented in earthy matrix; basaltic gravel cemented in calcareous matrix.	Generally poorly permeable, or do not carry water.
Pleistocene volcanic rocks	Pahala Ash	Yellow ash a few inches to 5 feet thick. Lies chiefly on southern slope of the mountain.	Relatively impermeable, and where interbedded with lava perches small quantities of water in wet areas.
	Hawi Volcanic Series	Dense lava flows, mostly thick-bedded andesite; cinder cones; domes of andesite and trachyte where viscous lava flows issued; andesite and trachyte dikes.	Clinker phases of lava flows are highly permeable, but dense parts transmit water poorly and in a few areas perch water. Cinder is highly permeable but contains little water. Domes are poorly permeable. Dikes impound water at high levels in lava.
Erosional unconformity in places			
Pliocene (?) volcanic rocks	Pololu Volcanic Series	Thin-bedded basalt lava flows, and a few thin interbedded tuff beds, separated from overlying Hawi Volcanic Series by a fossil soil a few inches to several feet thick; cinder cones; basaltic dikes and sills.	Lava flows are highly permeable and freely yield water to basal wells and to high-level springs and tunnels in the dike complex. Soil at top of Pololu Volcanic Series gives rise to many perched springs. Cinder is highly permeable but does not carry water. Dikes impound water at high levels in lava.

Table 6. Stratigraphic Section of Mauna Kea
(After Stearns and Macdonald, 1946, and Macdonald and Davis, 1956)

Major geologic unit	Rock assemblages	General character	Water-bearing properties
Recent (Holocene) sedimentary rocks	Fluvial gravel deposits	Poorly consolidated gravels deposited as alluvial fans along southern base of Mauna Kea and as shifting bars along present streams.	Poorly permeable as a whole.
Recent (?) (Holocene) volcanic rocks	Upper member of the Laupahoehoe Volcanic Series	Few cinder cones and lava flows on upper slopes of Mauna Kea.	Highly to moderately permeable, but yield no water.
Pleistocene sedimentary rocks	Fluvial and glacial conglomerates	Conglomerates forming terraces in lower parts of large valleys, and sheets of debris over part of southern slope of Mauna Kea.	Poorly to moderately permeable; yield a little water to dug wells at coast.
Pleistocene volcanic rocks	Lower member of the Laupahoehoe Volcanic Series	Cinder cones; massive dense lava flows of andesite and basalt; viscous domes; and thick deposits of ash overlying lava flows.	Cinder is highly permeable but does not yield ground water. Lava flows are moderately permeable and carry a little water perched by ash beds or dense flows. Ash is highly permeable but does not yield ground water.
	Pahala Ash	Friable ash composed chiefly of palagonitized dust- to sand-sized shards of volcanic glass and pumice lapilli.	Generally less permeable than associated lavas; perches a little water where buried by lava flows.
Upper Tertiary (?) and Pleistocene volcanic rocks	Hamakua Volcanic Series	Thin-bedded lava flows of basalt and andesite.	Moderately to highly permeable. Locally a little water is perched by ash beds or dense flows. Yield basal water freely to wells and springs.

Surface Water

Streams flow perennially to sea between Waipio and Pololu, fed by abundant rainfall on this swampy uplands of Kohala Mountains. Delayed runoff from the swamps, supplemented by discharge from springs at lower elevations, sustain the flow of the streams during dry periods.

Streams are not perennial northwest of Pololu, mainly because rainfall is insufficient to maintain streamflow.

Streams between Ookala and Waipio are not perennial despite considerable rainfall because the surface rocks of Mauna Kea are extremely permeable.

The Upper- and Lower-Hamakua ditches divert water from the tributaries of Waipio Stream. The Upper ditch, which runs along the rim of the deep canyons, diverts most of the water that flows in the uplands. This water goes mostly to south Kohala (Area V) for irrigation purposes. The Lower ditch runs along the foot of the deep canyons and captures discharge made up mainly of spring discharges.

Summary of surface water in Area I

Measured	Mgd	Mgd
Wailua Stream ----------------------------------	48	
Lower Hamakua ditch ---------------------------	31	
Upper Hamakua ditch (mostly to south Kohala) --	12	
Streams between Waimanu and Waikaloa ------------	20	
Kohala-Awini ditch ----------------------------	27	
Kehena ditch ----------------------------------	8	
Honokane Nui Stream ---------------------------	17	
Subtotal --------------------------------		163
Estimated		
Waimanu Stream ---------------------------------	30	
Streams between Waikaloa and Honokane Nui (in excess of water diverted by Awini ditch) ------	10	
Streams between Niulii and Upolu Point ----------	25	
Streams between Laupahoehoe and Waipio Valley ---	200	
Subtotal --------------------------------		265
Total -----------------------------------		428

Ground Water

Ground water occurs as basal water near sea levels and at high levels as dike-impounded water and as perched water. Maps showing streams, ditches, wells, springs, and tunnels in Kohala Mountains and in the area between Ookala and Kukuihaele are shown in figures 12 and 13.

Basal Water

The absence of a caprock and high permeability of the lavas along the coast of the Kohala Mountains causes the basal-water level to stand nearly at sea level. There is, however, a considerable amount of recharge to the basal-water body owing to the heavy rainfall in the uplands on the windward side of the mountain. Visible flow of 1 mgd from basal springs has been reported in Waipio, Waimanu, and Pololu Valleys, located between Kukuihaele and Niulii. The total discharge of basal water along this rugged coast is many times the visible flow of 1 mgd. The flow is smaller along the shores of the drier areas stretching from Niulii west to Upolu Point.

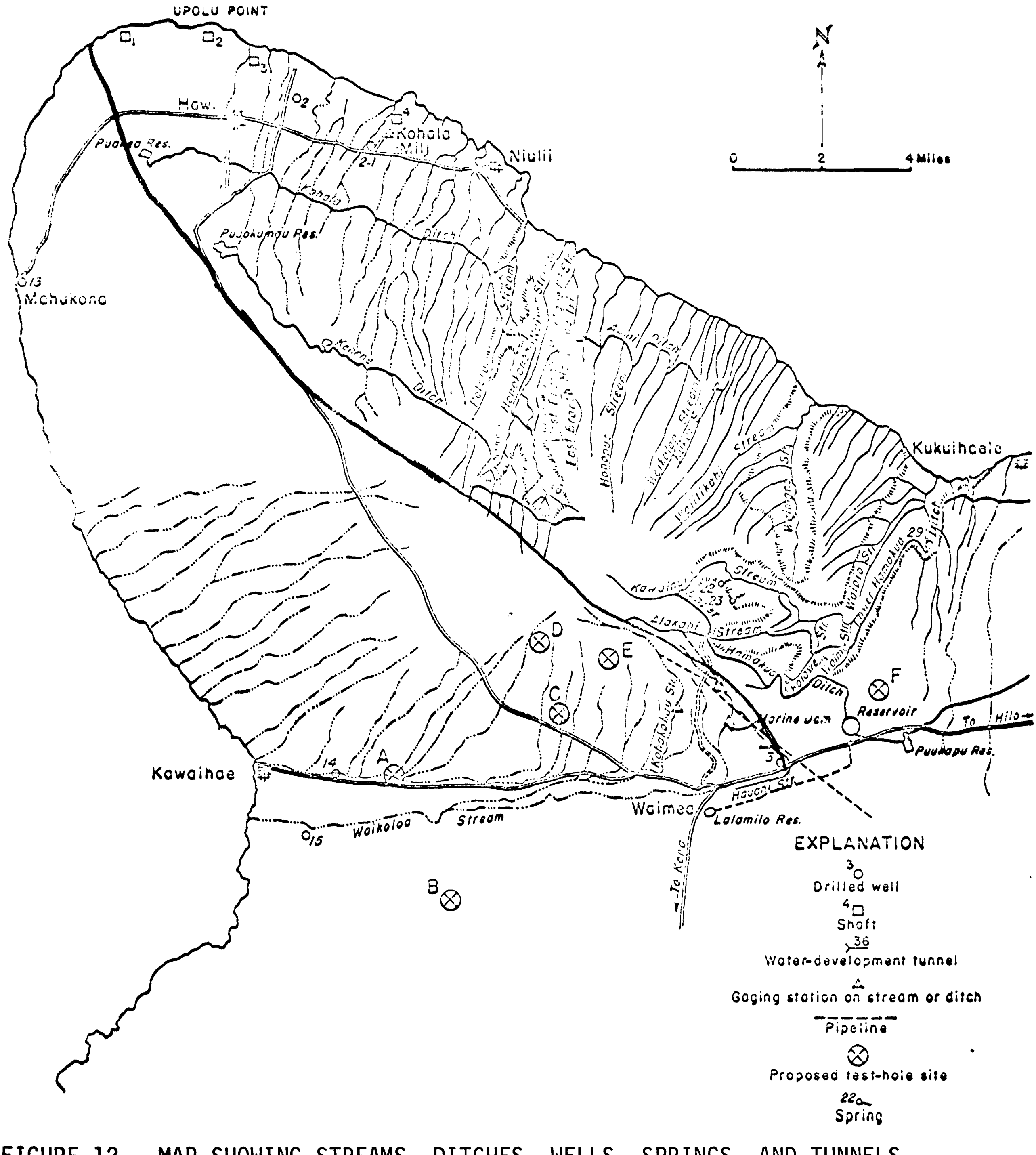


FIGURE 12. MAP SHOWING STREAMS, DITCHES, WELLS, SPRINGS, AND TUNNELS IN KOHALA MOUNTAIN.

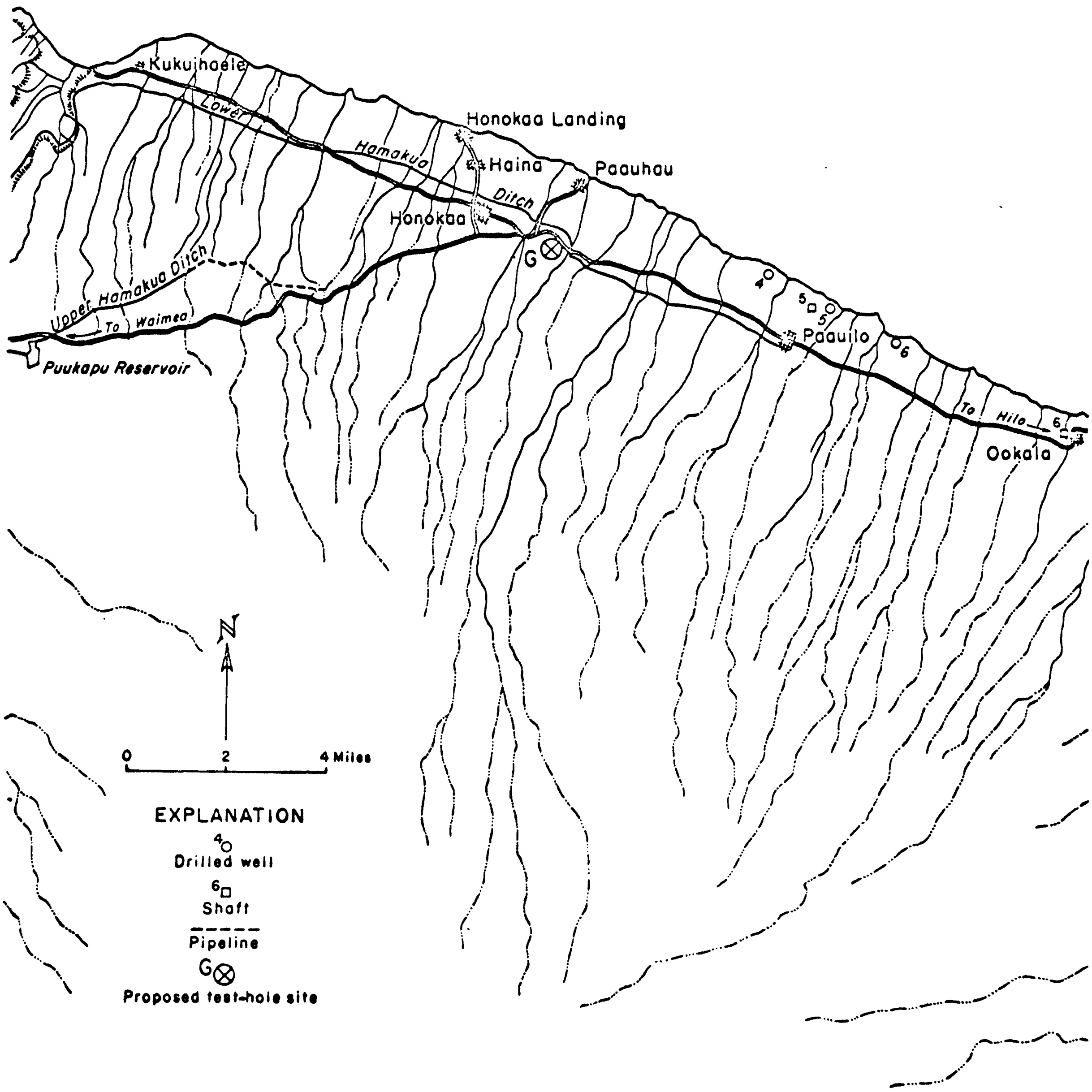


FIGURE 13. MAP SHOWING WELLS ON NORTHEASTERN SLOPE OF MAUNA KEA BETWEEN KUKUIHAELE AND OOKALA.

Laupahoehoe to Kukuihaele.--Basal-water discharge along this coast is roughly estimated at 50 mgd. The estimate is based on the following disposition of rainfall input:

	Average mgd
Input	
Rainfall	640
Imported water	40
Output	
Runoff	200
Evapotranspiration and irrigation	430
Surplus to basal ground water	50

Between 3 and 4 mgd is developed by shafts in Ookala and Paauilo.

Kukuihaele to Niulii.--The total basal-water discharge between Kukuihaele and Niulii is roughly estimated at 250 mgd. There are no wells in this area tapping this source of water. About 1 mgd of this discharge is visible as spring flow in Waipio, Waimanu, and Pololu Valleys. The figure of 250 mgd was derived on the basis of the following deposition of the rainfall input in the area.

	Mgd	Percentage of rainfall
Input		
Rainfall ----------------------------------	650	100
Output		
Runoff[a/] ----------------------------------	200	31
Evapotranspiration[b/] ---------------------	200	31
Surplus to basal ground water[c/] -------------	250	38

a/ Includes base flow of 110 mgd. An average of 40 mgd is exported for sugarcane irrigation along the Hamakua Coast and about 35 mgd is exported for sugarcane irrigation in north Kohala.

b/ Average rainfall is about 135 inches per year; evapotranspiration was estimated at 40 inches per year.

c/ Surplus is assumed to be discharged as basal spring flow or as basal underflow to sea. The 250-mgd figure is roughly equivalent to 20 mgd per shoreline mile.

Niulii to Upolu Point.--The basal-water table in the area slopes westward at a gradient of about 2-1/2 feet per mile toward Upolu Point. Highest basal-water levels in wells are about 8 feet above mean sea level. The chloride content of the water from pumped wells increases sharply seaward and westward toward Upolu Point.

Average pumpage of basal water is about 8 mgd, ranging annually from 2 to 14 mgd. Most of the water is used to irrigate sugarcane, and only a small amount is pumped for domestic supply. Unless other uses of the water can be found, the pumpage will decline to almost zero with the termination of sugarcane operations at the end of 1974.

Owing to the large acreage in irrigated sugarcane fields, most of the water is lost to evapotranspiration. About 35 mgd of water is imported from the area between Waikaloa Stream and Niulii. The total unused basal-water discharge is estimated at 10 mgd on the basis of the following computations.

	Mgd
Input	
Rainfall	140
Imported water	35
Output	
Runoff	25
Irrigation and evapotranspiration	140
Surplus to basal ground water	10

The surplus to basal ground water will increase significantly with the termination of sugarcane irrigation, owing to a large decrease in the demand for water by evapotranspiration.

Dike-Impounded Water

The source of the large base flows of Waipio, Waimanu, and Honokane Nui Streams and their tributaries is dike-impounded ground water. The visible average base flow discharge of dike-impounded water has been estimated at about 100 mgd. The estimated distribution of the discharge by altitude, is given in the following tabulation.

Approximate discharge of dike-impounded water into Kohala mountain streams

Altitude (ft)	Discharge above altitude shown (mgd)
0	100
500	65
1,000	40
1,500	25
2,000	15
2,500	10
3,000	5

Present Use of Water

Surface Water

The surface waters derived from the abundant rainfall on the wet slopes of the Kohala Mountains have been extensively developed.

Lower Hamakua ditch diverts about 31 mgd from the Wailoa Stream basin for the irrigation of sugarcane lands on the northern end of the Hamakua Coast.

Upper Hamakua ditch diverts about 12 mgd from the upper lands of the Wailoa Stream basin for domestic and agricultural use in the Kamuela area in Area V.

The Kohala-Awini ditch system diverts about 27 mgd from the streams in uninhabited areas east of Honokane for the irrigation of sugarcane lands in north Kohala west of Pololu Valley.

Kehena ditch is capable of diverting about 8 mgd for stock and irrigation use in the northwestern sections of Kohala.

Ground Water

Some ground water is developed by several tunnels and used for sugarcane irrigation in north Kohala. An estimated 200,000 gpd (gallons per day) of ground water is developed from three tunnels in north Kohala, springs near Kukuihaele, and a well in north Kohala and near Kawaihae. About 8 mgd of basal water is pumped for the irrigation of sugarcane in north Kohala.

Development and use of basal ground water between Niulii and Upolu Point began in the late 1800's. Since then, four large wells, consisting of tunnels at the bottoms of shafts sunk to sea level, were constructed for the irrigation of sugarcane. The latest was constructed in 1920 near Upolu Point. In 1948, a well for domestic supply was drilled in north Kohala.

Ground water perched on beds of ash and soil occurs in discontinuous, mostly small water bodies that supply numerous springs and seeps. The discharge of the springs fluctuates greatly, owing to the generally small storage of the water bodies.

Perched water in Pololu rocks is the source of numerous springs between Kukuihaele and Niulii. About 1 mgd of perched water in the Hawi rocks discharges as spring flow near the head of Kawainui Stream.

The estimated average flow of perched water from springs and tunnels between Niulii and Upolu Point is 4 to 5 mgd. Maximum flow is about 17 mgd and the minimum is about 1 mgd.

Potentials for Development

Surface Water

With extensive expenditures, some of the estimated 30 mgd not now diverted from the streams on the northeastern slopes of the Kohala Mountains probably could be diverted to the arid lands in the northwestern areas of Kohala. However, much further investigations should precede any plans to do so.

Ground Water

Laupahoehoe to Kukuihaele.--Ground-water flow, between Laupahoehoe and Kukuihaele, has been estimated at 4 mgd per shoreline mile. Mixing of seawater with fresh water is likely near the coast. Wells should be located some distance from the coast. Near shore, wells should be as shallow as possible below sea level.

Kukuihaele to Niulii.--About half or 360 mgd of the rainfall input of 650 mgd enters ground-water reservoirs. Of the 360 mgd, about 110 mgd discharges in streams as the ground-water component of the streamflow. A small part discharges from perched-water bodies along truncated cliffs near shore. The remaining 250 mgd discharges as underflow to sea. A small part of this underflow probably discharges to sea north of Niulii.

The tabulated discharge of dike-impounded water into Kohala Streams, shown in the section on dike-impounded water, gives a rough percentage of the ground water available at the different altitudes in the deeper stream channels. The relation between discharge and altitude should be used with caution and only applied in the mountainous interior where water is impounded by dikes. Near the coast where mostly basal-water conditions prevail, most of the rocks above sea level are unsaturated.

Owing to the large basal-water flux of approximately 20 mgd per mile of shoreline, mixing of seawater with the fresh is minimal. A large percentage of the flow can be recovered by wells scattered along the coast.

Niulii to Upolu Point.--The best area for additional development of ground water is in the southern part of the area near Niulii. The water-level gradient, which slopes northwesterly, indicates there is some underflow of ground water from the adjacent wetter area to the south and east.

Otherwise, the potential of developing large new sources of ground water in much of the area is small. This could significantly change if sugarcane irrigation terminates and the demands for evapotranspiration by sugarcane greatly decreases.

Area II

This area is about 1,240 square miles in area and comprises the eastern slopes of Mauna Kea, Mauna Loa, and Kilauea. Aside from forest reserves in the middle and upper slopes, the principal land use is sugarcane cultivation. Sugarcane fields occupy most of the lower slopes up to an altitude of about 2,000 feet. This level generally lies at least 3 miles inland from the shore.

Geology

The bulk of Mauna Kea is made up of rocks of the Hamakua Volcanic Series, which consist of basaltic and andesitic lava flows. Above the Hamakua rocks is the Pahala Ash, composed of discontinuous beds of volcanic glass and pumice.

The youngest rocks are those of the Laupahoehoe Volcanic Series, which are made up of a lower member of andesitic and basaltic lava flows, and an upper member of cinder cones and some andesitic flows. The Laupahoehoe rocks are mainly on the upper slopes of the mountain; only a few flows of the lower member extend down to the lower slopes.

Dikes are probably numerous in the interior of the volcano, but only a few have been exposed by erosion.

The areal distribution of rocks in the area is shown in figure 14. The sequence of rocks and their water-bearing properties are given in the table on page 55.

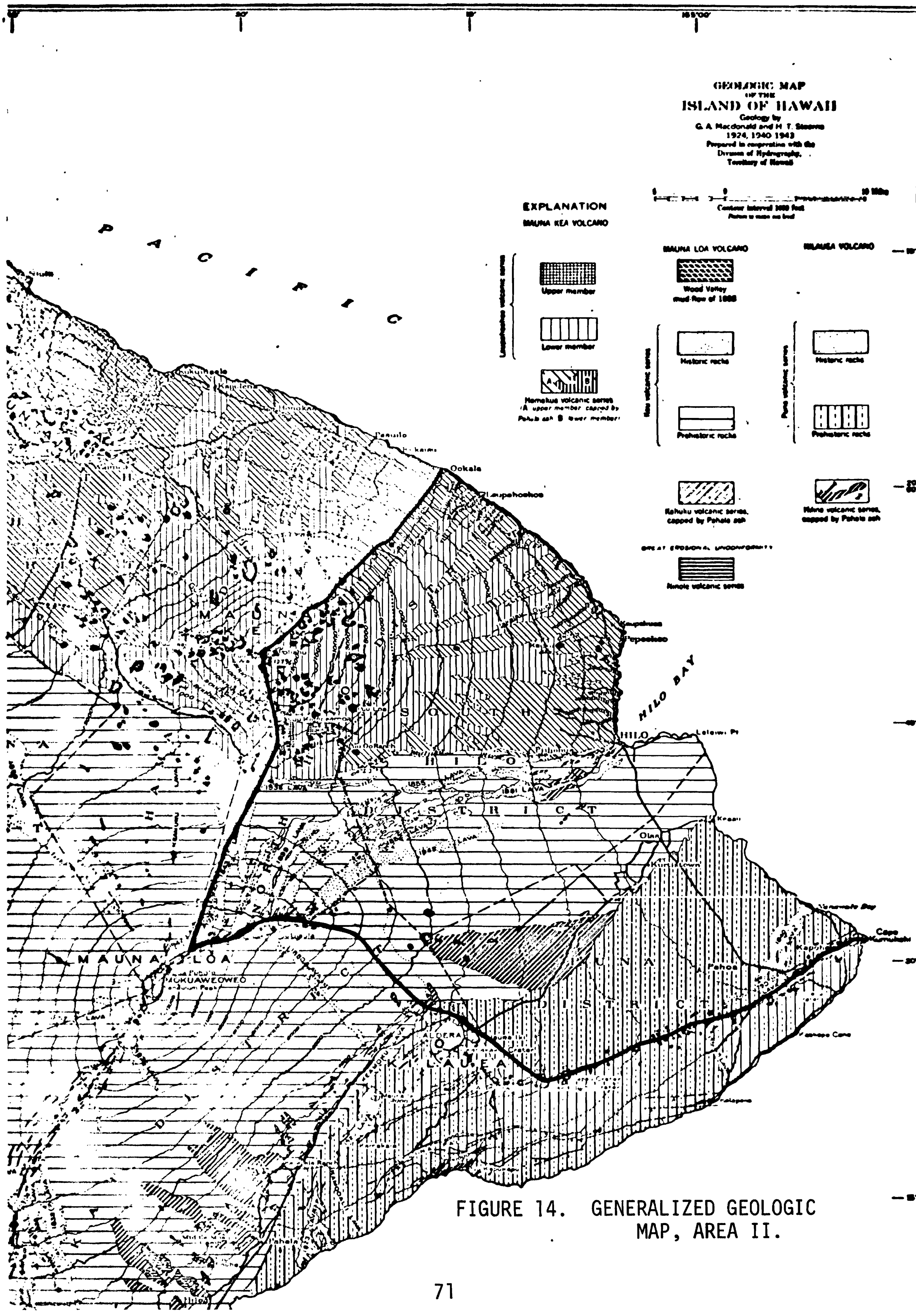


FIGURE 14. GENERALIZED GEOLOGIC MAP, AREA II.

Mauna Loa.--Mauna Loa is composed mainly of basaltic lava flows. A few layers of ash are interbedded in the flows. Some vents are marked by cinder and spatter. Dikes are probably numerous deep in the rift zone, but none are visible except in the summit area. Sedimentary deposits consist of minor amounts of basaltic and calcareous sands at the shore and small patches of alluvium in a few stream channels.

Lava flows of the Ninole Volcanic Series form the bulk of Mauna Loa, but is concealed by a veneer of lava flows of the Kahuku Series, the Pahala Ash, and flows of the Kau Series. The lava flows of all Series are mostly thin-bedded and are moderately to highly permeable. The Pahala Ash is mostly fine-grained and commonly has low permeability.

The distribution of rocks is shown in figure 14, and the sequence of the rocks is given in the following table.

TABLE 7. STRATIGRAPHIC SECTION OF MAUNA LOA VOLCANO

(After Stearns and Macdonald, 1946, p. 67)

Major Geologic Unit	Rock Assemblage	General Character	Water-bearing Properties
Recent (Holocene) and Pleistocene volcanic rocks	Historic member of Kau Volcanic Series	Aa and pahoehoe. Thin narrow flows on flanks of the mountain; massive flows in Mokuaweoweo Caldera. Cinders and spatter at vents; littoral cones at shore; lava fill in pit craters.	Extremely permeable but carry no water except at coast, where it is brackish.
	Prehistoric member of Kau Volcanic Series	Aa and pahoehoe flows forming a nearly complete veneer over Mauna Loa. Cinders and spatter at vents; littoral cones at shore; pit craters; thin ash deposits leeward of vents.	Extremely permeable. Large springs discharge at shore, but much of water along arid coast is brackish. Locally in wet areas contain water perched on Pahala Ash.
Pleistocene volcanic rocks	Pahala Ash	Red to yellow, friable ash, 12 to 50 feet thick; in places separated into 2 or more beds by intercalated lava flows.	Relatively impermeable in finer textured phases. In wet uplands, ash perches water in overlying lava and gives rise to high-level springs.
	Kahuku Volcanic Series	Aa and pahoehoe flows. Cinder cones at vents; littoral cones at shore; pit craters.	Highly permeable; carries brackish water near shore, but may contain fresh water near sea level farther inland. Locally, in wet uplands, lava flows carry water perched by intercalated ash beds.
		Great erosional unconformity	
Pliocene or older volcanic rocks	Ninole Volcanic Series	Aa and pahoehoe flows, partly altered by weathering. A bed of well-consolidated, fine-grained tuff is interstratified with lava about 550 feet below top of series.	Basalt is highly permeable and carries fresh water at sea level and perched water above tuff bed, which is nearly impermeable.

Kilauea.--The area includes the eastern slopes of Kilauea and part of its eastern rift zone. The distribution of Kilauea rocks is shown in figure 14 and the stratigraphic relations of these rocks are given in the following table.

Rainfall

More than half of the rainfall for the island falls in this area, 3,133 mgd on the slopes of Mauna Kea north of Hilo, and 4,200 mgd in the south Hilo section. The distribution of mean annual rainfall in the area is shown in figure 15. Rainfall is highest on the windward side of Mauna Kea, between altitudes of 2,000 and 4,000 feet. It decreases rapidly above and below this belt and dies away rapidly from the ends of it. Mean annual rainfall ranges from about 15 inches near the summit of Mauna Kea to more than 300 inches in the zone of high rainfall.

TABLE 8. STRATIGRAPHIC SECTION OF KILAUEA VOLCANO
(After Stearns and Macdonald, 1946, p. 100-101)

Major Geologic Unit	Rock Assemblage	General Character	Water-bearing Properties
Recent (Holocene) and latest Pleistocene volcanic rocks	Historic member of Puna Volcanic Series	AA and pahoehoe. Thin narrow flows on flanks of the mountain; massive flows in caldera. Lithic ejecta a few inches to several feet thick around south rim of caldera. Cinder and spatter cones at vents; littoral cones at shore; lava fill in pit craters.	Extremely permeable, but carry no water except at shore where it is brackish.
	Prehistoric member of Puna Volcanic Series	Friable ash and explosion debris. Aa and pahoehoe nearly completely covering the surface of Kilauea. Cinder and spatter cones at vents; littoral cones at shore; pit craters.	Extremely permeable, but carry mostly brackish water along dry southern coast.
Pliocene or older volcanic rocks	Pahala Ash	Yellow friable ash 10 to 60 feet thick. Caps basalt of Hilina Volcanic Series, except in face of cliffs, and crops out in kipukas in the Puna Volcanic Series.	Relatively impermeable and may perch water locally in wet areas.
	Hilina Volcanic Series	Aa and pahoehoe.	Highly permeable, but carry only brackish water along shore.

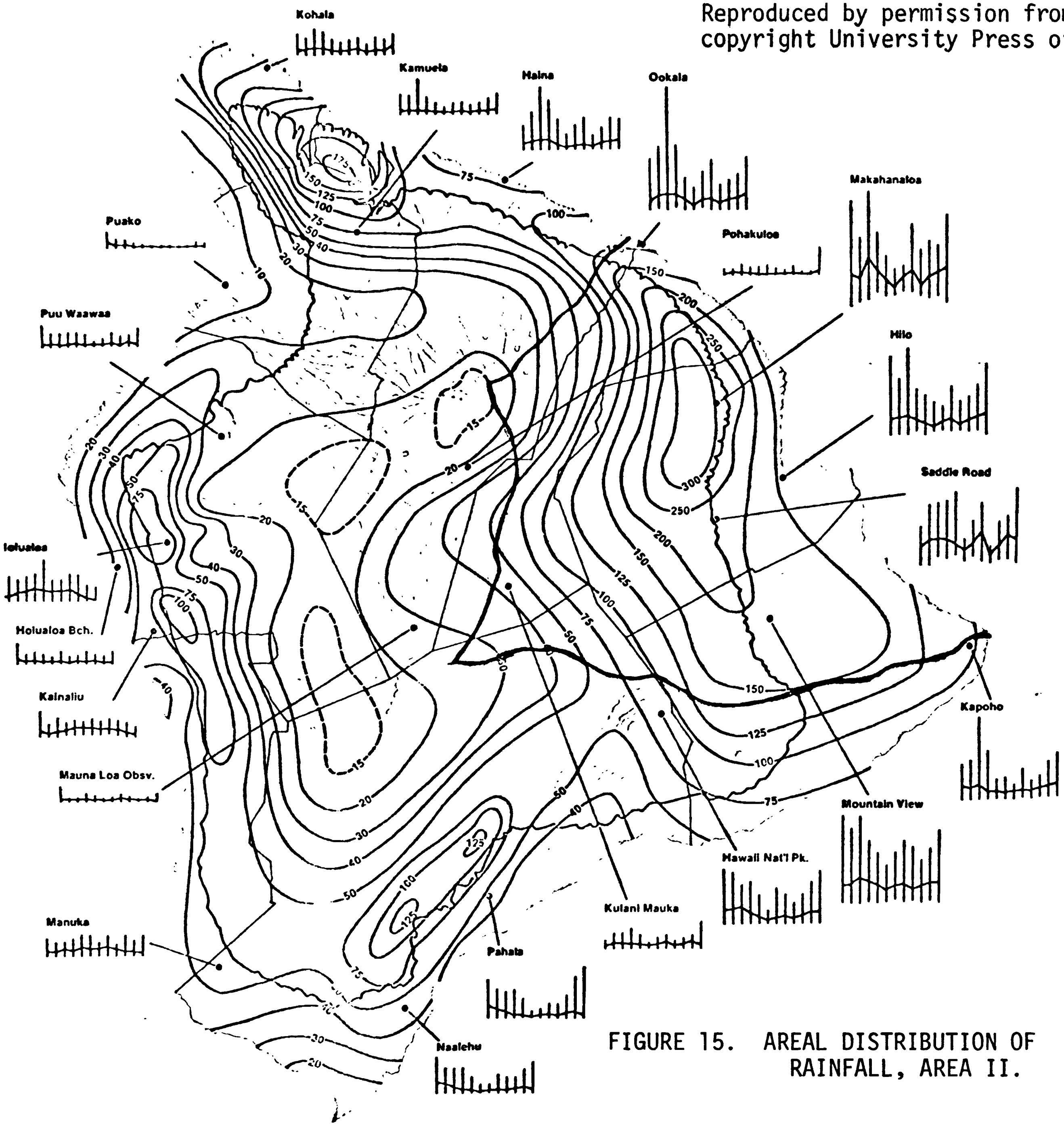
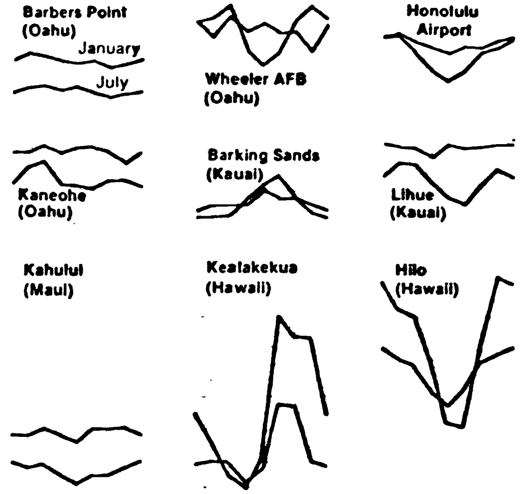


FIGURE 15. AREAL DISTRIBUTION OF RAINFALL, AREA II.

RAINFALL FREQUENCY BY HOUR OF DAY

Three Hour Intervals Centered at Hour Shown



The diurnal variation in rainfall frequency differs from place to place in Hawaii, since it represents a complex interplay between terrain and wind—both the large-scale flow and the local air movements produced by day-to-night temperature contrasts between land and sea. In places well exposed to the trade winds, showers are usually more frequent during the night and early morning (for example, Lihue in July), reflecting conditions over the open sea or an interaction between the trades and nocturnal offshore land breezes. In contrast, areas sheltered from the trade winds (like Kealakekua, in Hawaii Island's Kona district) tend to have their rainfall maximums in late afternoon and evening, from showers that form within sea breezes which move onshore and upslope during the day.

Although Hawaii has considerably more gages than almost any other area of comparable size, the rainfall of its inaccessible or uninhabited regions remains largely conjectural. Nor is nearly enough known about the effects of smaller terrain features or about contrasts in rainfall between adjoining ridges and valleys.

Surface Water

Streams on the slopes of Mauna Kea, near Hilo, flow perennially to the sea in spite of the extremely permeable ground surface. Rainfall on the slopes between the 2,000- to 4,000-foot altitude is so abundant and well distributed that more water is available than can percolate into the ground.

The principal streams in this area are the tributaries to Wailuku River, and Honolii, Kapue, Kawainui, Kolekole, Hakalau, Umauma, and Pohakupuka Streams.

In aggregate, streamflow into the ocean is estimated to be about 2,000 mgd, mostly unused since the practice of fluming cane stalks to mills was discontinued. Some surface water is still being used for domestic purposes or for mill operations.

Measured flow in Hamakua area	Mgd
Wailuku River	183
Diversion from Wailuku River	3.9
Kapehu Stream	33
Kapehu ditch	1.5
Honolii Stream	84
Alia Stream	8
Pohakupuka Stream	18
Total	233

Measurements at other streams above the 1,000-foot altitude made during dry weather in 1962 amounted to 25 mgd.

While the rainfall is considerable in the forested northeast slopes of Mauna Loa, the water sinks rapidly into the ground, and no perennial streams exist except where perching structures of either weathered ash beds or dense lava flows keep the water from percolating down to the basal-water body. The springs that issue from the perched-water bodies maintain the base flows of several tributaries to Wailuku River. The flow of Waiakea Stream is also maintained by perched-water bodies, but the water in this stream sinks into the ground before it can reach Hilo Bay. As is typical for springs fed by perched-water bodies of limited extent, the flow fluctuates widely, responding almost directly to rainfall.

Ground Water

Ground water occurs as basal water, perched water, and, most likely, as dike-impounded water deep in the rift zone. Figures 16 and 17 show the occurrence of ground water, well locations, and the chloride content of the water in wells.

Basal Water

Large quantities of basal ground water flow into the ocean at or near the shore along the Hamakua Coast. The flow is largest in the area between Hilo and Laupahoehoe. Near Pepeekeo, downgradient from the high-rainfall zone, water levels near the coast range from about 5 to 8 feet above mean sea level. Near Ookala and Paauilo, about 25 miles northwestward from Pepeekeo, water levels near the coast fluctuate between 2 and 5 feet above mean sea level.

The average pumpage of basal ground water in the area is 3 to 4 mgd, most of it from shafts in Ookala and Paauilo for sugarcane cultivation and processing.

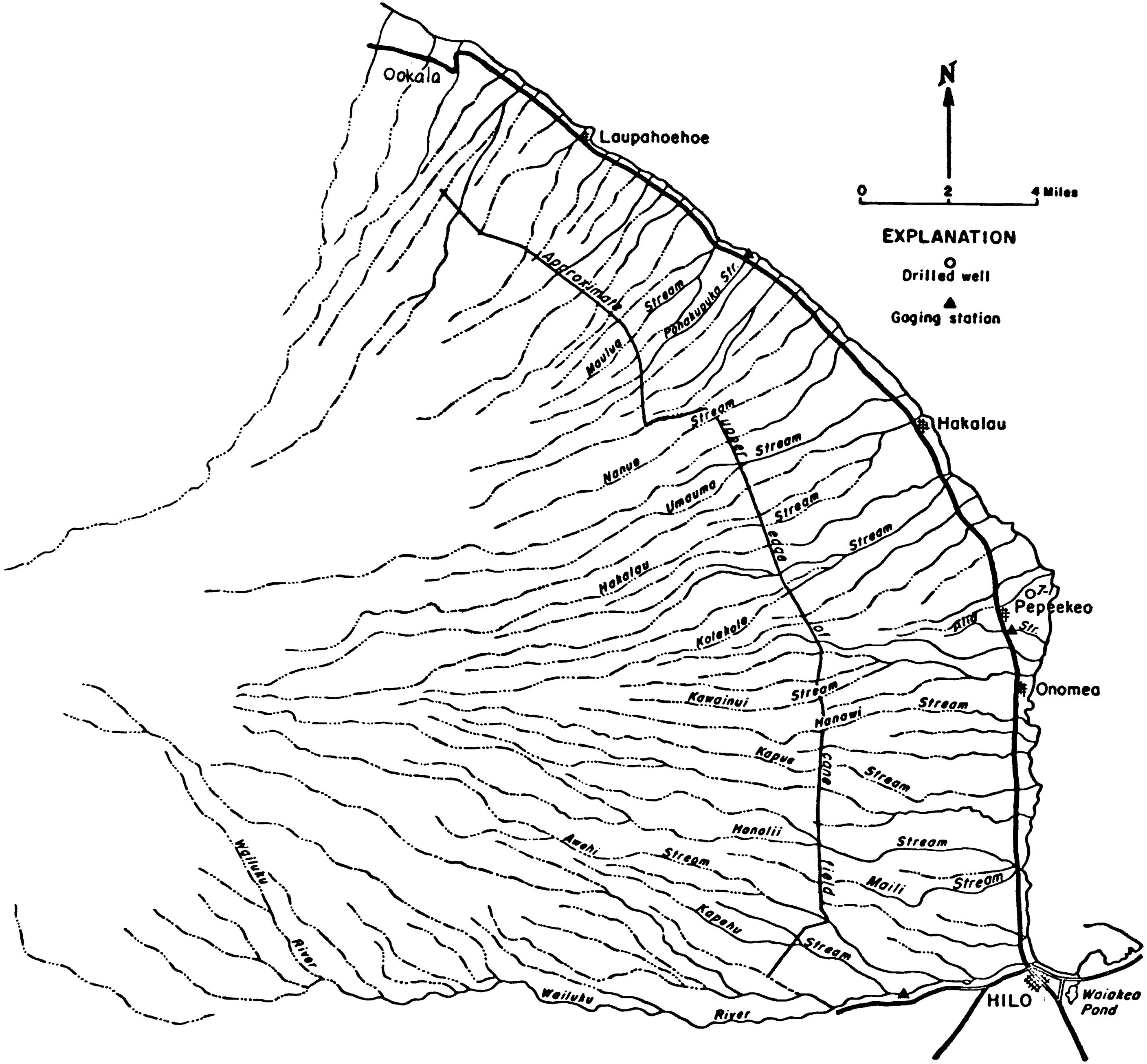
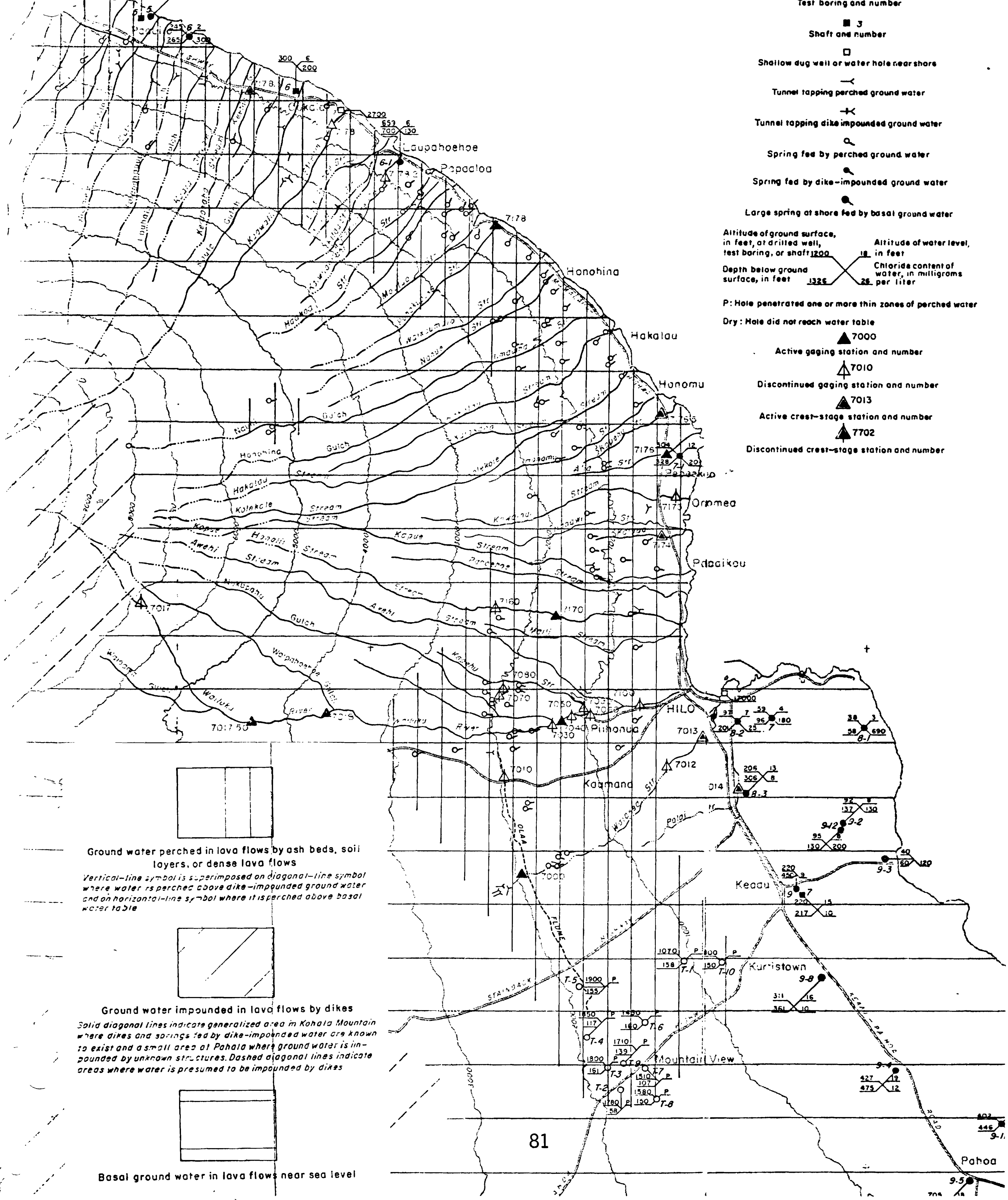


FIGURE 16. MAP SHOWING WELLS ON NORTHEASTERN SLOPE OF MAUNA KEA BETWEEN LAUPAHOEHOE AND HILO.

Figure 17. OCCURRENCE OF GROUND WATER, WELL LOCATIONS, AND CHLORIDE CONTENT OF WATER NEAR HILO.



Hilo to Laupahoehoe.--The total basal-water discharge from Mauna Kea lavas between Hilo and Laupahoehoe is estimated at roughly 750 mgd or 38 mgd per shoreline mile. This supply is not developed except for about 0.2 mgd used for domestic purposes. The figure of 750 mgd was derived on the basis of the following disposition of the rainfall input.

	Mgd		Percentage of rainfall	
	Range	Average	Range	Average
Input				
Rainfall ----------------		3000		100
Output				
Runoff[a] ----------------	1500-2100	1800	50-70	60
Evapotranspiration and irrigation ------------	300- 600	450	10-20	15
Surplus to basal ground water --------------------	1200- 300	750	40-10	25
Ground-water flow per shoreline mile -----------	38			

a/ Includes base flow of streams.

Basal water of variable quality underlies all the south Hilo area, except possibly where dikes may impound water in rift zones. The visible discharge of basal water is 300 to 400 mgd. Total discharge, however, is several times this amount, most of it issuing in diffused flow at sea level. The largest visible concentrations of flow are in the Hilo area.

The discharge of basal water is likely confined to the coast between Cape Kumukahi and Hilo. The east rift of Kilauea probably prevents underflow to the south, and the contact of Mauna Kea lavas and the basal water contained therein prevents underflow to the north.

Records of wells show that the water level rises from sea level at the shore 2 to 4 feet per mile and is generally 12 to 18 feet above sea level, 5 to 6 miles inland.

Most basal water at the shore is brackish because of mixing with seawater. Salinity decreases with distance inland, but the decrease is irregular. The lines of equal chloride content of basal water shown in figure 18 were drawn from data available from about 23 drilled wells.

The total basal-water discharge between Cape Kumukahi and Hilo is roughly estimated at 2,300 mgd. The figure of 2,300 mgd was derived on the basis of the following disposition of the rainfall input.

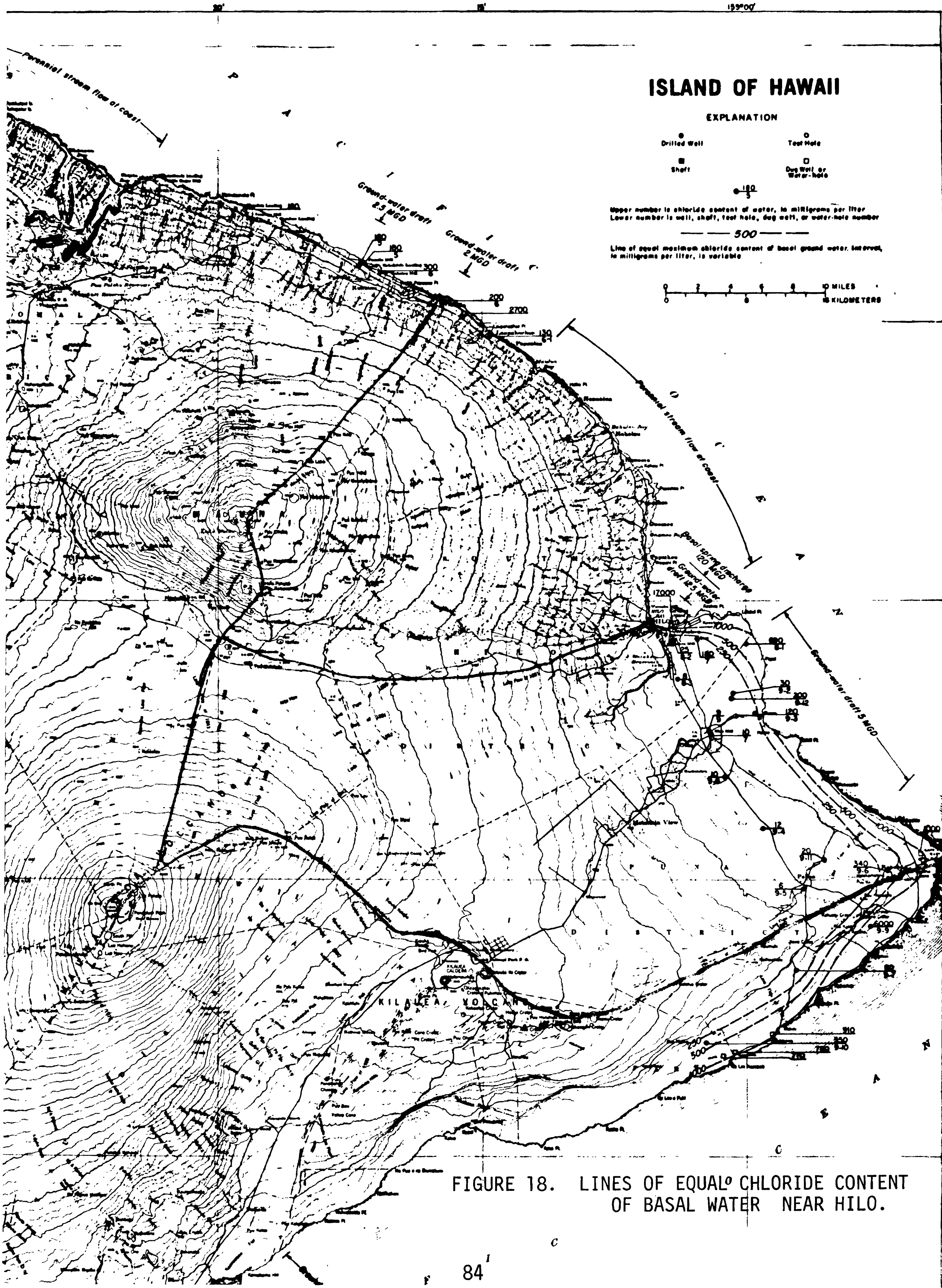


FIGURE 18. LINES OF EQUAL CHLORIDE CONTENT OF BASAL WATER NEAR HILO.

	Mgd	Percentage of rainfall
Input		
Rainfall	4,200	100
Output		
Runoff[a/]	630	15
Evapotranspiration[b/]	1,260	30
Surplus to basal ground water	2,310	55
Ground-water flow per shoreline mile[c/]	100	

a/ Basal-water inflow near coastal areas not included.

b/ Evapotranspiration of 30 percent is roughly 42 inches per year.

c/ Flow decreases from north to south.

Dike-Impounded Water

Dikes in the interior parts of Mauna Kea, Mauna Loa, and Kilauea probably impound a great volume of water, but no valleys are deep enough to intersect these water bodies. The depths to dike-impounded water are too great and preclude development at reasonable cost.

Perched Water

There are numerous perched-water bodies scattered at shallow depths along the windward slopes of Mauna Kea. There are many springs originating from these water bodies. Most are small, but some of the discharges range up to 0.4 mgd. The aggregate spring discharge from perched-water bodies is about 7 mgd. The greatest number of springs and the largest flows are in the southern part of the area between Hilo and Laupahoehoe.

About 25 tunnels have been constructed to develop perched water. Most of their yields are small, and some flow only during wet weather. Perched springs contribute substantially to the low flow of perennial streams. Overflow discharge of springs in the subsurface recharges the basal-water body.

Perched water in the south Hilo area has been developed in areas of discharge by diversions at springs and by means of tunnels dug along or near the tops of perching members. Flow from tunnels, like that of springs, fluctuates widely. Total flow of perched-water sources in the south Hilo area is less than 1 mgd.

Owing to the large fluctuations in flow, prospects of developing large additional amounts of perched water are not encouraging. Small amounts, however, could be delivered by gravity flow to a considerable part of the lower east slope of Mauna Loa.

Prospects of developing perched water are better on the slopes of Mauna Loa than on the slopes of Kilauea.

Present Use of Water

Surface Water

Since the discontinuance of the practice of fluming cane stalks from fields to mills, the use of surface water in the northern section has been limited to domestic use and for mill use.

In the south Hilo area, water from Kahoama Stream, a tributary of Wailuku River, supplies an average of 3.8 mgd of domestic water to the Hilo water system and the Waiakea Stream supplies about 0.15 mgd. The total water available at the intake is deficient during drought periods.

Hilo Electric Co. diverts an average of 48 mgd from Wailuku River for the generation of hydro-electric power.

Ground Water

In the northern section, some perched ground water is developed by tunnels and used mostly for the irrigation of sugarcane and some for domestic supply. Some spring discharges originating from shallow perched-water bodies are developed and used for domestic supply in the wet areas between Hilo and Laupahoehoe.

Basal water is pumped from shafts in Ookala and Paauilo, mostly for use in sugarcane cultivation and processing. A small quantity of basal water is pumped for domestic supply in Pepeekeo.

A map showing wells between Hilo and Ookala is included in figure 17.

In the south Hilo area, basal water is pumped from wells to supply domestic water for the communities of Kapoho, Pahoa, Olaa, Mountain View, and Hilo. Total municipal pumpage is about 4 mgd, of which 3 mgd is pumped from two wells in the Hilo area. In addition, about 10 mgd of basal water is pumped from wells in the Olaa area for sugarcane operations, which include irrigation and processing.

The Waiakea-Uka Spring, a perched-water spring, provides about 0.2 mgd of domestic water for Hilo.

Large quantities of basal water is used for cooling in the Hilo area by Hilo Electric Co. The heated water is returned to the ground in seepage pits.

Potentials for Development

Surface Water

While large quantities of surface water flow to the sea in wet weather, suitable sites for storing storm flows are scarce in the northern section, limited by steep slopes and porous streambeds. Dry-weather flow is in excess of the present demands but the cost of diverting and transporting this water may be economically infeasible, at least under present conditions.

In the south Hilo area, because of the porous nature of the rocks in the area, surface runoff is only a small portion of rainfall and streamflow, during the drier part of the year, is limited to portions of Wailuku River and Waiakea Stream.

Investigations, including the streamflow measurements in 1965-66 of Wailuku River, indicated that during dry periods, the river reaches a local maximum of about 0.25 mgd at an altitude of about 3,700 feet before losing all its water to seepage as it flows downstream. It flows again farther downstream.

Ground Water

The unused basal-water flow to the ocean between Hilo and Laupahoehoe probably represents the largest unused source of ground water in the State. Ground-water flow has been estimated at 38 mgd per shoreline mile. At this high-discharge rate, mixing of seawater with the fresh, even near the shore, is unlikely.

In the south Hilo area, owing to the exceptionally large basal-water flow of approximately 100 mgd per mile of shoreline, the best potential for developing large supplies of ground water is basal water. Mixing of seawater with the fresh is small. Exception is in the area immediately east and southeast of Hilo Bay because this area is immediately downgradient from the large discharge (sink) of basal water into the bay. Elsewhere, some mixing near coastal areas occur because of the highly permeable nature of the lava flows adjoining the ocean.

For small supplies at high altitudes, the development of perched water appears feasible. The advantage of occurrence of perched water at high altitudes is offset by recurrent periods of deficient flow, a lack of easy means of regulating flow, and a wide scatter of perched-water sources.

Area III

This area is about 913 square miles in area and comprises the southeast slope of Mauna Loa and the south and west slopes of Kilauea.

Geology

The rocks of Mauna Loa include lava flows and pyroclastic deposits of three volcanic series. The oldest, the Ninole Volcanic Series, forms the bulk of the mountain that has been almost completely buried by later flows of Mauna Loa. The Kahuku Volcanic Series lies uncomformably on eroded Ninole rocks and underlies the Pahala Ash. The Pahala Ash everywhere overlies the Kahuku flows. Dikes cutting lava flows are exposed in the walls of craters in the summit area, but erosion has not been deep enough to expose dikes in the flanks of the mountain.

Along the southeastern base of Mauna Loa, the Honuapo-Kaoiki fault system   is a series of echelon tangential faults, which the mountainside has relatively moved upward. This fault system probably plays a significant role in channeling ground water southwestward toward Punaluu.

The distribution of rocks are shown in figure 19. Their sequence and water-bearing properties are given in table 7.

East of the Honuapo-Kaoiki fault system, all of the rocks are from the Kilauea volcano, except for minor amounts of beach deposits.

Kilauea is built of the lava and ash deposits of two volcanic series, the Hilina and the Puna. Hilina rocks make up the bulk of Kilauea, but they are exposed only in small windows in the overlying younger Puna rocks. Above the Hilina rocks and separating them from Puna rocks is the Pahala Ash, which is concealed by the Puna rocks, except at exposures of the Hilina.

Ash is widespread on the surface and ranges in thickness from less than an inch on the lower flanks to several feet at the summit.

The distribution of the principal rock types is shown in figure 19 and their stratigraphic relations are given in table 8.

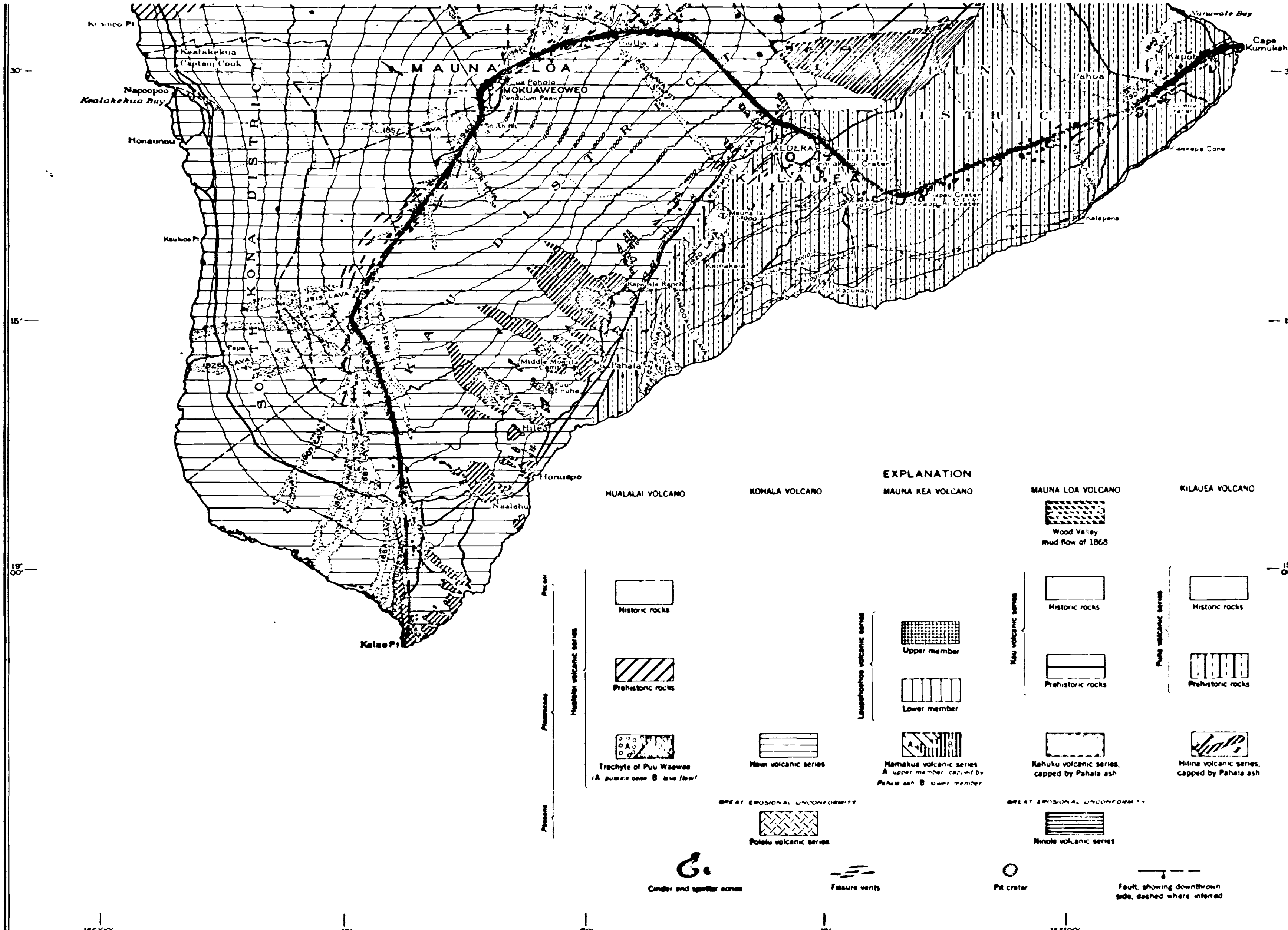


FIGURE 19. GENERALIZED GEOLOGIC MAP, AREA III.

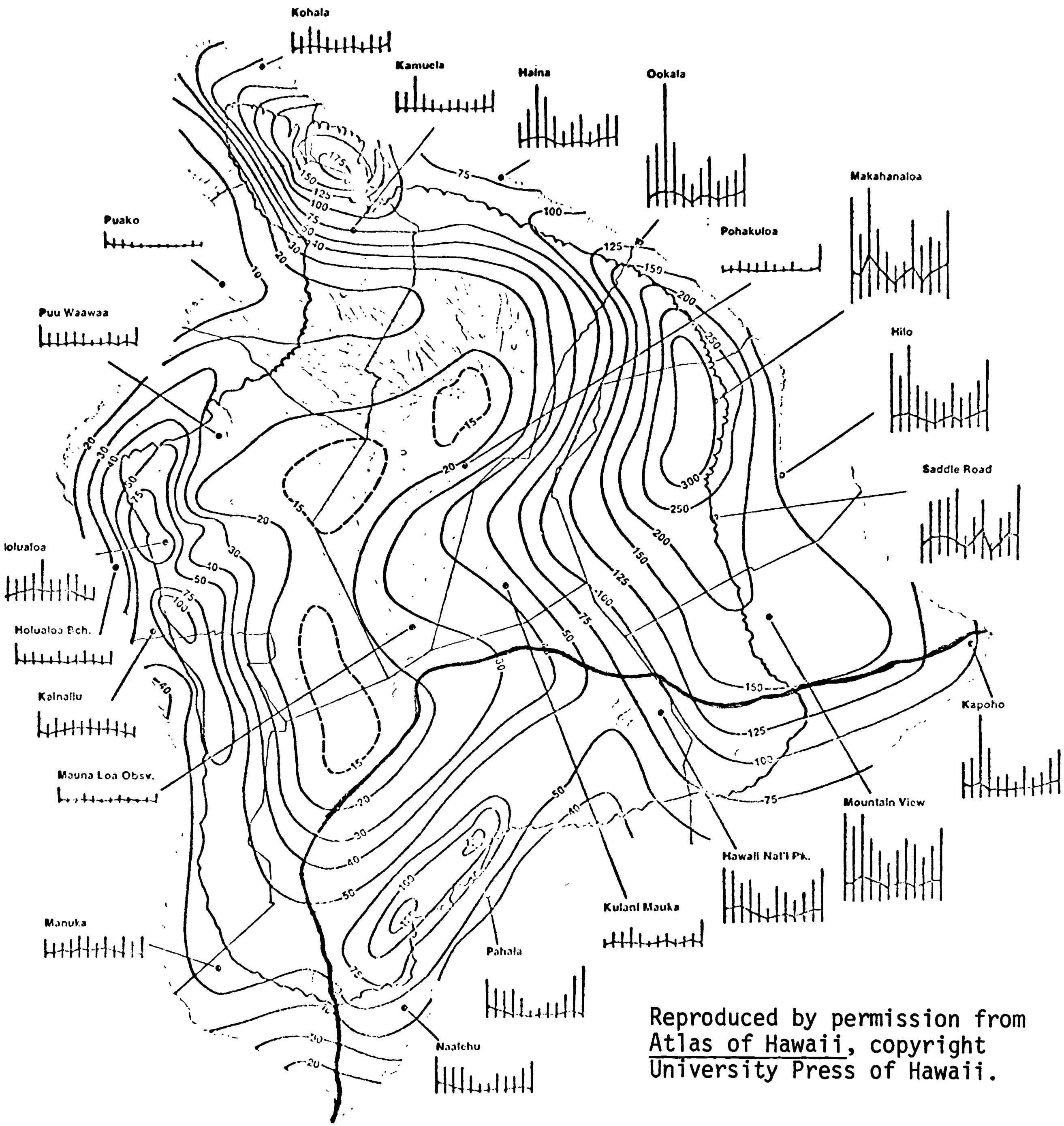
Rainfall

On the slopes of Mauna Loa, the highest rainfall, about 125 inches per year, occurs at about an altitude of 3,000 feet. Rainfall decreases below and above this altitude. Half or more of the rain in the rainy area occurs between May and September of each year. In the drier areas, the reverse is true, where most of the rainfall occurs in the winter months.

On the basis of the rainfall map shown in figure 20, rainfall in the area was computed to average 1,307 mgd.

The eastern part of the Kilauea sections lies to the south of a high-rainfall belt, west of Hilo, and receives some of the orographic rainfall. The western part, in contrast, receives little of the orographic rainfall. Much of the rainfall in the western part results from convective-type showers. Rainfall in the eastern part ranges from about 50 to about 185 inches per year. In the western part, the range is from about 40 to about 75 inches per year.

On the basis of the rainfall map shown in figure 20, rainfall in the area was computed to average 1,040 mgd.



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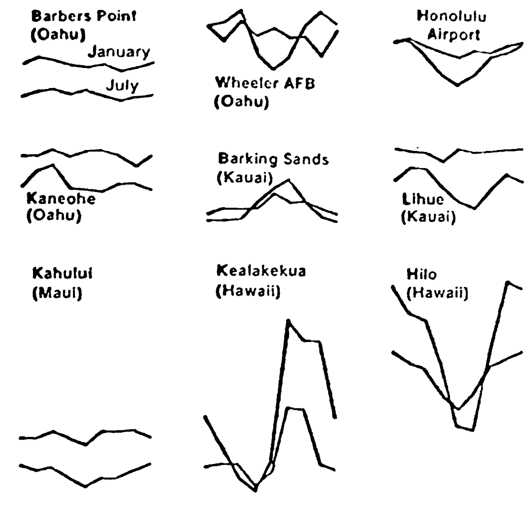
RAINFALL FREQUENCY BY HOUR OF DAY

Three Hour Intervals Centered at Hour Shown



The diurnal variation in rainfall frequency differs from place to place in Hawaii, since it represents a complex interplay between terrain and wind—both the large-scale flow and the local air movements produced by day-to-night temperature contrasts between land and sea. In places well exposed to the trade winds, showers are usually more frequent during the night and early morning (for example, Lihue in July), reflecting conditions over the open sea or an interaction between the trades and nocturnal offshore land breezes. In contrast, areas sheltered from the trade winds (like Kealakekua, in Hawaii Island's Kona district) tend to have their rainfall maximums in late afternoon and evening, from showers that form within sea breezes which move onshore and upslope during the day.

Although Hawaii has considerably more gages than almost any other area of comparable size, the rainfall of its inaccessible or uninhabited regions remains largely conjectural. Nor is nearly enough known about the effects of smaller terrain features or about contrasts in rainfall between adjoining ridges and valleys.

FIGURE 20. AREAL DISTRIBUTION OF RAINFALL, AREA III.

Surface Water

While there are no streams that flow perennially into the sea, there is enough rainfall in a section of the southeastern slopes of Mauna Loa to result in sufficient outflow from either swampy lands or from springs emanating from perched ground-water bodies to maintain nearly continuous flow in the headwaters of several streams in that section.

Measured surface flow in southern Mauna Loa

	Mgd
Hilea Gulch tributaries ----------------------	7.2
Ninole Streams -------------------------------	2.7
Paauau Streams -------------------------------	0.4
Total ----------------------------------	10.3

There are no perennial streams in the Kilauea section. Rains, up to 185 inches per year, sink into fresh lava surfaces.

Ground Water

Ground water in Mauna Loa lava flows at high levels is perched on ash and tuff and is impounded in at least one thick water body by an unknown structural feature. It also occurs as basal water near sea level. The area is outside the boundary of known major rift zones, so the likelihood of the ground water being dike-impounded is small.

Locations of wells and other water sources and areas proposed for test drilling by Dan A. Davis in 1966 are shown in figure 21. The occurrence of ground water, the chloride content of water from ground-water sources, and the dimension of the wells are also shown in the figure.

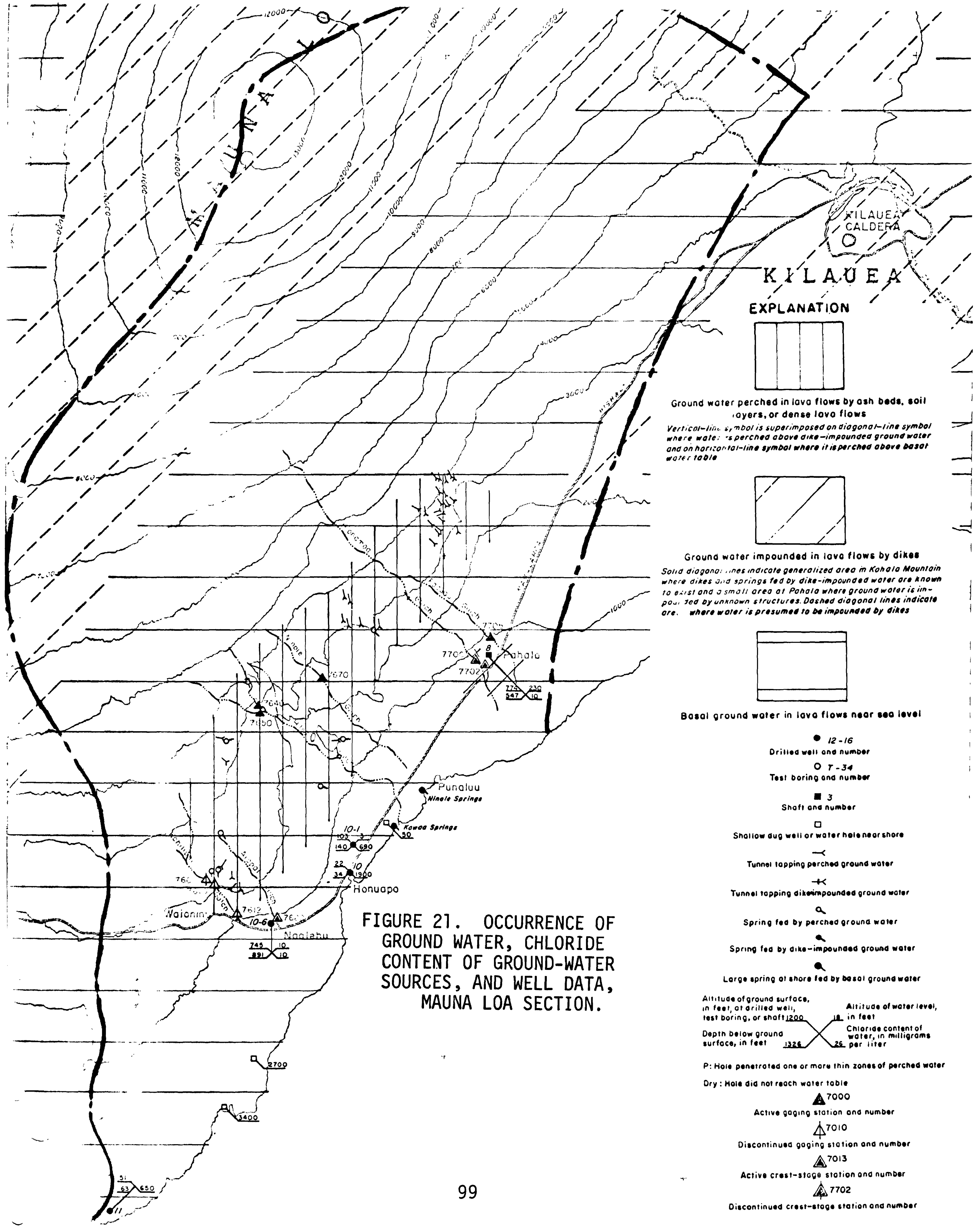


FIGURE 21. OCCURRENCE OF GROUND WATER, CHLORIDE CONTENT OF GROUND-WATER SOURCES, AND WELL DATA, MAUNA LOA SECTION.

Ground water occurs as basal water and as dike-impounded water deep in the rift zone of Kilauea. Owing to light rainfall in general, perched-water bodies, although numerous, are mostly short-lived.

The area is largely isolated from Mauna Loa in that little ground water in Mauna Loa rocks move downgradient into Kilauea rocks. The geologic structures, responsible for the hydrologic barriers, are the Honuapo-Kaoiki fault system and the rift zones of Kilauea. This means that nearly all recharge to ground water must originate as rainfall in the area.

The occurrence of ground water, the chloride content of water from ground-water sources, and the other well data are also shown in figure 22.

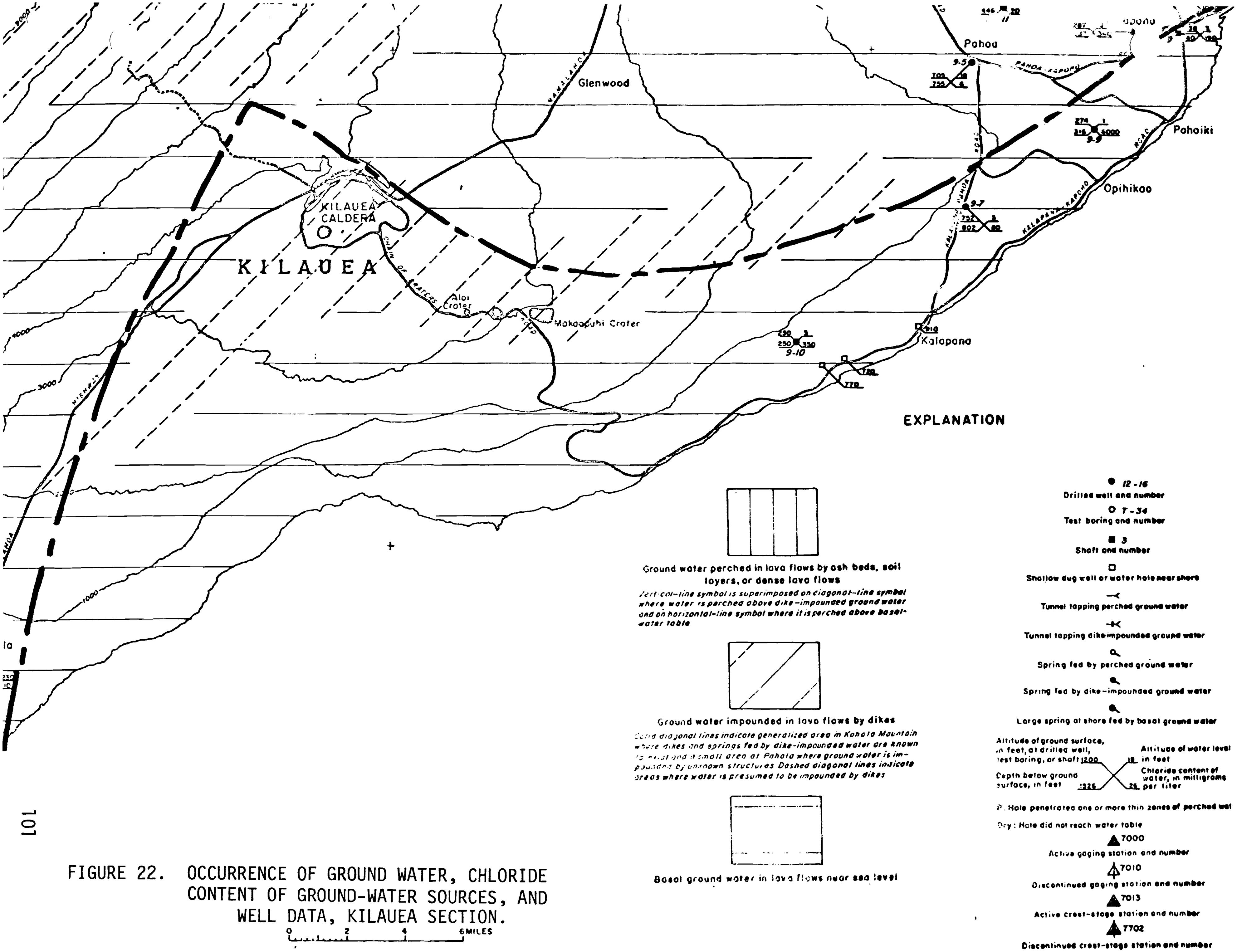


FIGURE 22. OCCURRENCE OF GROUND WATER, CHLORIDE CONTENT OF GROUND-WATER SOURCES, AND WELL DATA, KILAUEA SECTION.

Basal Water

Mauna Loa Section.--Large basal ground-water flows discharge at the shore from lavas at Ninole and Kawaa Springs (fig. 21). The flow of Ninole Springs has been measured at 27 and 29 mgd. The water contains 300-400 mg/l chloride. The discharge of Kawaa Spring has been measured at about 13 mgd. Water in wells inland of Kawaa Springs has a chloride content less than 100 mg/l.

Southwestward from Kawaa Springs, the discharge at the shore becomes less and the chloride content higher. The chloride content of the water from a well near Waikapuna Bay is about 2,000 mg/l, and at Waipouli, 3,000 feet from the shore, it is about 1,800 mg/l.

It is quite possible that the Honuapo-Kaoiki fault system channels ground water southwestward toward Punaluu, and the ancient buried valleys upgradient from Ninole and Kawaa Springs prevent the channeled ground water from continuing southwestward. The large flow of the Ninole and Kawaa Springs may be the result of such a channeling and impoundment.

Basal ground water is developed in several wells and water holes near the shore.

The flow to sea of fresh basal water between Punaluu and Honuapo has been estimated at 30-50 mgd. This quantity represents about 5 percent of all the rain that falls in the area east of Honuapo.

The total rainfall in the area amounts to roughly 1,300 mgd. Stream runoff is low but evapotranspiration is high owing to many shallow perched-water bodies and sugarcane irrigation near Honuapo. If rough estimates of 10-percent runoff and 75-percent evapotranspiration were deducted from the rainfall input, the surplus would be approximately 200 mgd. About 75 percent of this surplus, or about 175 mgd, occurs in the area east of Honuapo. If the Honuapo-Kaoiki fault system is successful in channeling at least 50 percent of this water, then the fresh basal-water flow is somewhat greater than the 30-50 mgd previously estimated--perhaps to a quantity of about 80 mgd. If the fault system is highly effective in channeling flow, then the discharge flow may be on the order of 175 mgd. If not, whatever flow not channeled would discharge to the sea along the shore in the Kau area.

The ground-water flow southwest of Honuapo is estimated at 25 mgd or about 2 mgd per shoreline. Because of this low flux, much of the basal water underlying coastal areas is brackish.

Kilauea Section.--Discharge along the shoreline in the eastern part of Kilauea is small. The east rift zone of Kilauea forms a barrier to southward movement of ground water from the area of higher rainfall north of the rift zone. Discharge along the shoreline in the western part is likewise small. The Honuapo-Kaoiki fault and the southwest rift of Kilauea form a barrier to southeastward movement from the area of higher rainfall on the slopes of Mauna Loa.

Large supplies of fresh water are probably not available from the basal aquifer south of the Kilauea rift zone. The prospects are probably better in the area southeast of the Honuapo-Kaoiki fault system. In the area south of the rift zone, wells will yield water but generally having a chloride content greater than 300 mg/l. At or near the shore, water from wells will probably have a chloride content of 1,000 mg/l or more.

The area has a rainfall input of about 1,040 mgd and a shoreline of about 50 miles or equivalent to about 20 mgd per shoreline mile, if all of the rainfall were to discharge to the sea. If rough estimates of 10-percent runoff and 70-percent evapotranspiration were deducted from the rainfall total, the resulting shoreline discharge reduces to 4 mgd per mile. The total basal-water discharge would be approximately 80 mgd. This quantity assumes the Honuapo-Kaoiki fault system is an absolute hydrologic barrier. The groundwater flow diverted by the fault system is estimated at 175 mgd. Any leakage through the fault system will significantly increase the estimated flow of ground water in the Kilauea volcano area.

Owing to the highly permeable nature of the aquifer, all basal water is mixed with seawater near the coast. Fresh water is available in inland areas, but the distance may be such that the depths of wells needed to develop this water probably will exceed 1,000 feet and may even exceed 2,000 feet. Even where the water is fresh, the amount available per well may be limited because of the thin basal-water lens.

Dike-Impounded Water

The area is out of any known rift zones of the Mauna Loa volcano. The likelihood that ground water is dike-impounded is small. However, an apparent impounded body of water occurs in the Pahala area. The impounding geologic structures may be the Honuapo-Kaoiki fault system and the buried valleys perpendicular to the fault. The fault system is linear and is probably deep and may be as effective as dike in impounding or channeling ground water. The top of the water level is at 220 feet above mean sea level. The extent of the impounded water or structures is unknown. The water from this well is developed by two wells drilled to sea level from the bottom of a shaft.

Most of the discharge, however, is natural and furnishes recharge to basal-water bodies downgradient.

Dikes in the interior of Kilauea may impound water to considerable heights above sea level; however, exploration for or recovery of the water will be costly owing to its great depth below the surface.

Perched Water

A large quantity of water is perched in the upland area from Pahala to Naalehu. The water occurs in numerous irregular, discontinuous water bodies a few inches to a few feet thick, many of which discharge at seeps and small springs.

The perched-water bodies are irregular and discontinuous because of great variations in the thickness and permeability of the perching member. Tunnels dug to recover this water are generally crooked or on an uneven grade. Their lengths range from 100 to 7,000 feet.

Because of the small size in general, the discharge of the tunnels fluctuate widely with rainfall. Average flow of the tunnel has been estimated at between 6-10 mgd and the low flow at 1-2 mgd.

Water perched on ash beds may be present locally under the slopes of Kilauea, but none discharges at the surface. Any bodies of perched water in lava flows of Kilauea are probably thin and small. A pond several feet above sea level in Kapoho Crater may be fed by water perched on tuff. The pond was once used to supply local domestic- and irrigation-water needs.

Present Use of Water

Basal water is pumped for sugarcane irrigation and golf course irrigation on the slopes of Mauna Loa. Pumpage is about 3 mgd for sugarcane irrigation at Honuapo and about 1 mgd for golf course irrigation at Punaluu. Wells and water holes near the shore tapping basal water are used for stock supplies.

About 38 tunnels have been dug in the area, most of them yielding perched water from lava flows of the Ninole and Kahuku Volcanic Series. Most of the tunnels were originally dug for water to transport sugarcane in flumes from the fields to the mills. Presently, about 0.4 mgd of perched water is used for municipal supply.

High-level impounded water is pumped at a rate of about 3 mgd at Pahala.

In the Kilauea section, about 10,000 gallons per day of basal water are pumped for domestic use by the municipality. The projected use from this system is about 0.5 mgd.

Potentials for Development

Surface Water

Under present conditions, surface-water development is infeasible, inasmuch as perennial flows are limited in amount and occur only in short reaches within this rainy zone.

Ground Water

Large supplies of fresh ground water are available in the coastal area between Punaluu and Honuapo. Test drilling is needed to determine the best sites for development. Vertical hatching in figure 23 shows the area most favorable for exploration.

The potential decreases markedly southwest of Honuapo. Wells in this area should be located as far inland as feasible.

The high-level impounded water, which is tapped by a shaft at Pahala, is potentially a large source of water. Its natural discharge recharges basal-water bodies in the downgradient direction. Horizontal hatching in figure 23 shows the area favorable for exploration.

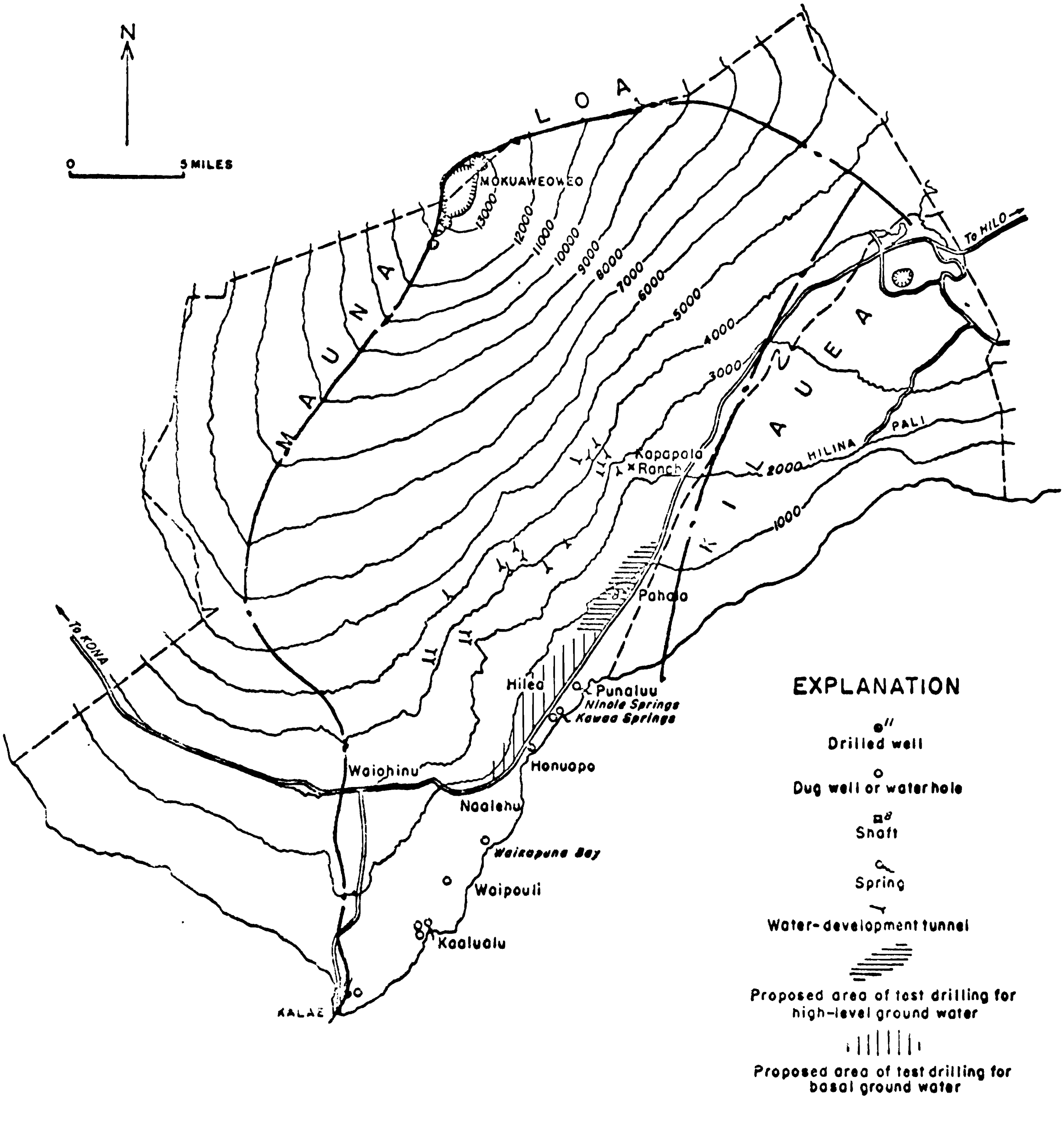


FIGURE 23. TOPOGRAPHIC MAP SHOWING AREAS FAVORABLE FOR EXPLORATION FOR GROUND WATER.

The prospects of obtaining large quantities of ground water are better on the western side of the Kilauea section than the eastern side. Least promising appears to be along the coast directly south of Kilauea Crater. The high-known water levels in the Pahala area to the west probably induces significant leakage across the Honuapo-Kaoiki fault system to recharge the aquifer lying to the southeast. In the eastern half, ground water is impounded by the rift zone and moves along the rift zone from west to east. Wells drilled near the rift zone will probably encounter better quality water than wells away from the rift zone. At or near the shore, water from wells will probably have a chloride content of 1,000 mg/l or more.

Area IV

This area is about 795 square miles in area and comprises the southern slopes of the Hualalai volcanic dome and the leeward slopes of Mauna Loa.

Geology

The rocks in this area emanated from Hualalai and Mauna Loa volcanoes. The distribution of the rocks is shown in figure 24.

Hualalai.--The bulk of the volcano consists of prehistoric basaltic lava flows of the Hualalai Volcanic Series. Cinder cones are scattered on the summit area and along the rift zones. Ash beds, ranging from a few inches to a few feet, mantle part of the mountain. The prehistoric basaltic lavas have generally high permeability.

Mauna Loa.--The area includes the west and northwest slopes of Mauna Loa. The bulk of the mountain is composed of thin-bedded basaltic lava flows, which, at the surface, is covered by a veneer of prehistoric and historic lavas of the Kau Volcanic Series. Cinder and spatter cones lie along the southwest rift of Mauna Loa, and dikes are probably buried deep in the rift zone. Thin ash deposits lie on parts of the slopes.

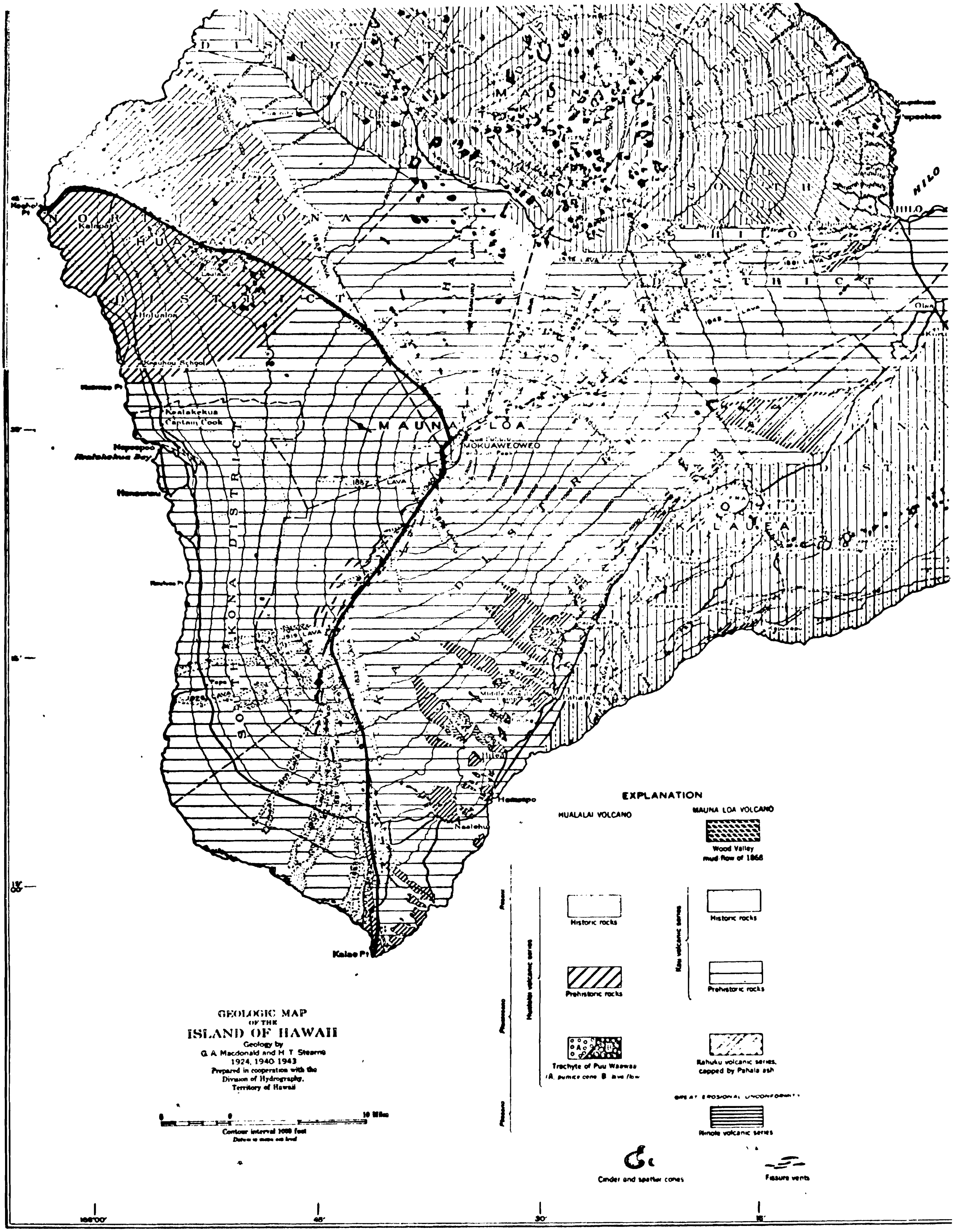


FIGURE 24. GENERALIZED GEOLOGIC MAP, AREA IV.

The sequence of rocks and their water-bearing properties are given in tables 7 and 9.

The basaltic lavas, which were erupted above sea level, are highly permeable and are saturated near sea level. Most of the older volcanoes have subsided considerably and much of the lavas presently situated below sea level was erupted above sea level. In an active volcano, such as Mauna Loa, subsidence may be minimal and much of the basaltic flows presently below sea level was erupted below sea level and, hence, not as permeable as lavas which erupted above sea level.

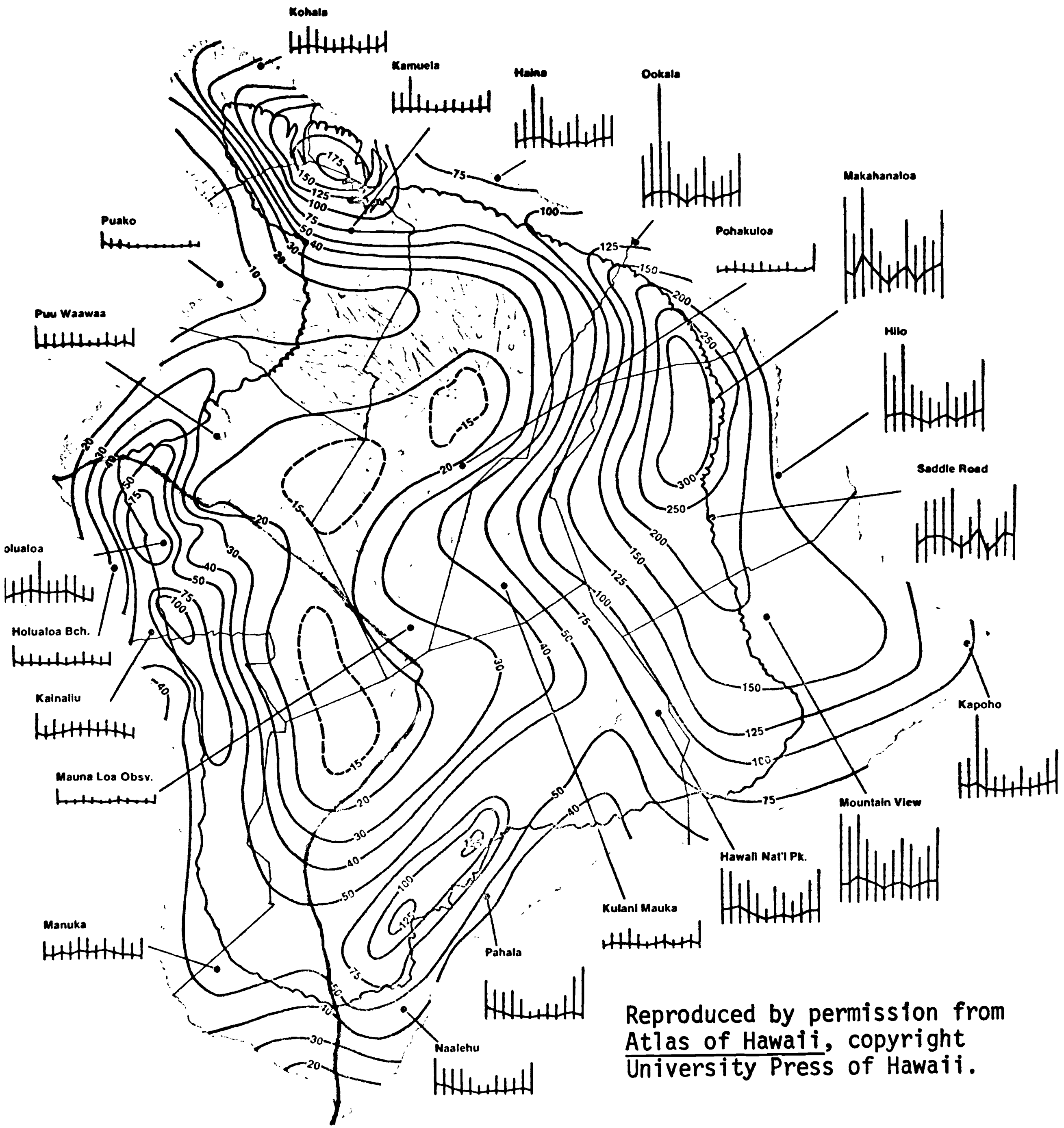
Rainfall

The western coast lies on the leeward side of the island, sheltered from the trade winds by the great height and breadth of Mauna Kea and Mauna Loa. The area receives little of the orographic trade-wind rainfall. However, much of the area has considerably more rainfall than other leeward parts of the Hawaiian Islands, owing to convective-type showers on the west slopes of Mauna Loa and Hualalai. The zone of greatest rainfall resulting from convective-type showers is on the leeward side of Mauna Loa and Hualalai at altitudes between 1,200 and 3,500 feet.

On the basis of the rainfall map shown in figure 25, rainfall in the area was computed to average 1,790 mgd.

Table 9. **Stratigraphic section of Hualalai**

Major geologic unit	Rock assemblage		General character	Water-bearing properties
Quaternary volcanic rocks	Flows and cones of 1800-1801, the historic member of the Hualalai volcanic series		Olivine basalt pahoehoe and aa flows carrying numerous dunite and gabbro xenoliths.	Extremely permeable but carry no water except at the coast, where it is brackish.
			Spatter cones and ramparts at the sources of the flows.	Highly permeable but carry no water.
	Prehistoric member of the Hualalai volcanic series. (Partly younger and partly older than the Waawaa volcanics)	Basalt member	Porphyritic and nonporphyritic basalt aa and pahoehoe flows ranging from 5 to 100 feet in thickness and averaging 20 feet.	Highly permeable, carrying brackish water near the coast but fresh water near sea level farther inland.
			Cinder and spatter cones at the source of the lava flows.	Highly permeable but carry no water.
			Vitric ash and cinder deposits.	Highly permeable but those at the surface carry no water.
		Waawaa volcanics (trachyte member)	Fine-grained trachyte aa partly covered with basaltic lavas and Pahala ash.	Poorly permeable and carries no water.
			Trachytic pumice cone at the source of the flow.	Permeable but carries no water.



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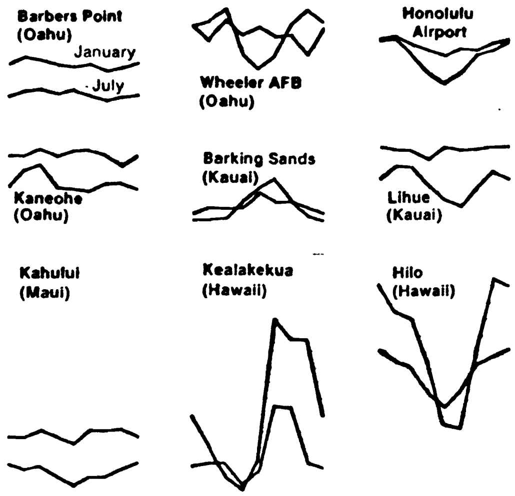
RAINFALL FREQUENCY BY HOUR OF DAY

Three Hour Intervals Centered at Hour Shown



The diurnal variation in rainfall frequency differs from place to place in Hawaii, since it represents a complex interplay between terrain and wind—both the large-scale flow and the local air movements produced by day-to-night temperature contrasts between land and sea. In places well exposed to the trade winds, showers are usually more frequent during the night and early morning (for example, Lihue in July), reflecting conditions over the open sea or an interaction between the trades and nocturnal offshore land breezes. In contrast, areas sheltered from the trade winds (like Kealakekua, in Hawaii Island's Kona district) tend to have their rainfall maximums in late afternoon and evening, from showers that form within sea breezes which move onshore and upslope during the day.

Although Hawaii has considerably more gages than almost any other area of comparable size, the rainfall of its inaccessible or uninhabited regions remains largely conjectural. Nor is nearly enough known about the effects of smaller terrain features or about contrasts in rainfall between adjoining ridges and valleys.

FIGURE 25. AREAL DISTRIBUTION OF RAINFALL, AREA IV.

Surface Water

There are no perennial streams in this area although Waiaka and Kiilae Streams have small flows most of the year within the rainy upland area.

Stations were installed at both streams near their point of maximum flow at normal times. Records show average flows of about 0.7 mgd for Waiaka Stream and about 0.1 mgd for Kiilae Stream.

This area is unique in the Region, in that unlike in other areas of the State, rainfall here is greater during the summer months than in the winter months, and streams are less likely to go dry in June than in December.

Ground Water

Basal Water

Basal ground water most likely underlies all of the area, except in the rift zones. Recharge of fresh water to the basal aquifer is moderate to large in the rainy zones on the western slopes but is small elsewhere.

The extent and storage of basal water in much of the Mauna Loa lavas depend somewhat on the degree of subsidence of the Mauna Loa volcano. If subsidence has been significant, basal-water storage is large in the interior; if not, extent and storage of basal water would be limited by the presence of low-permeability rocks below sea level.

All recharge to deep ground-water bodies eventually finds its way into basal-water bodies along the coast before being discharged to sea. Rainfall in the area amounts to roughly 1,790 mgd, which is equivalent to about 30 mgd per shoreline mile, if all of the rainfall were to discharge to sea. The rainfall equivalent of 30 mgd per shoreline mile ranges from about 20 mgd for areas fronting dry areas and about 50 mgd for areas fronting wet areas, as along the west slopes of Hualalai and Mauna Loa. If rough estimates of 10-percent runoff and 70-percent evapotranspiration were deducted from the rainfall total, the resulting shoreline discharge of basal water reduces to about 4 mgd per mile in the dry areas and to about 10 mgd per mile in the wet areas. The total basal-water discharge would be roughly 345 mgd.

The amounts are, however, only relative, although they can be used to delineate the more promising areas for basal-water development from the less promising. All basal water is mixed with seawater near the coast, owing to the highly permeable nature of the aquifers. The ground water near the shore is likely to be fresher in the wetter areas. This is quite important in steeply sloping areas, such as this, where much of the ground water is mixed along the coast, in places as much as 3 miles inland.

The chloride content of the water from basal-water sources in the area is shown in figure 26.

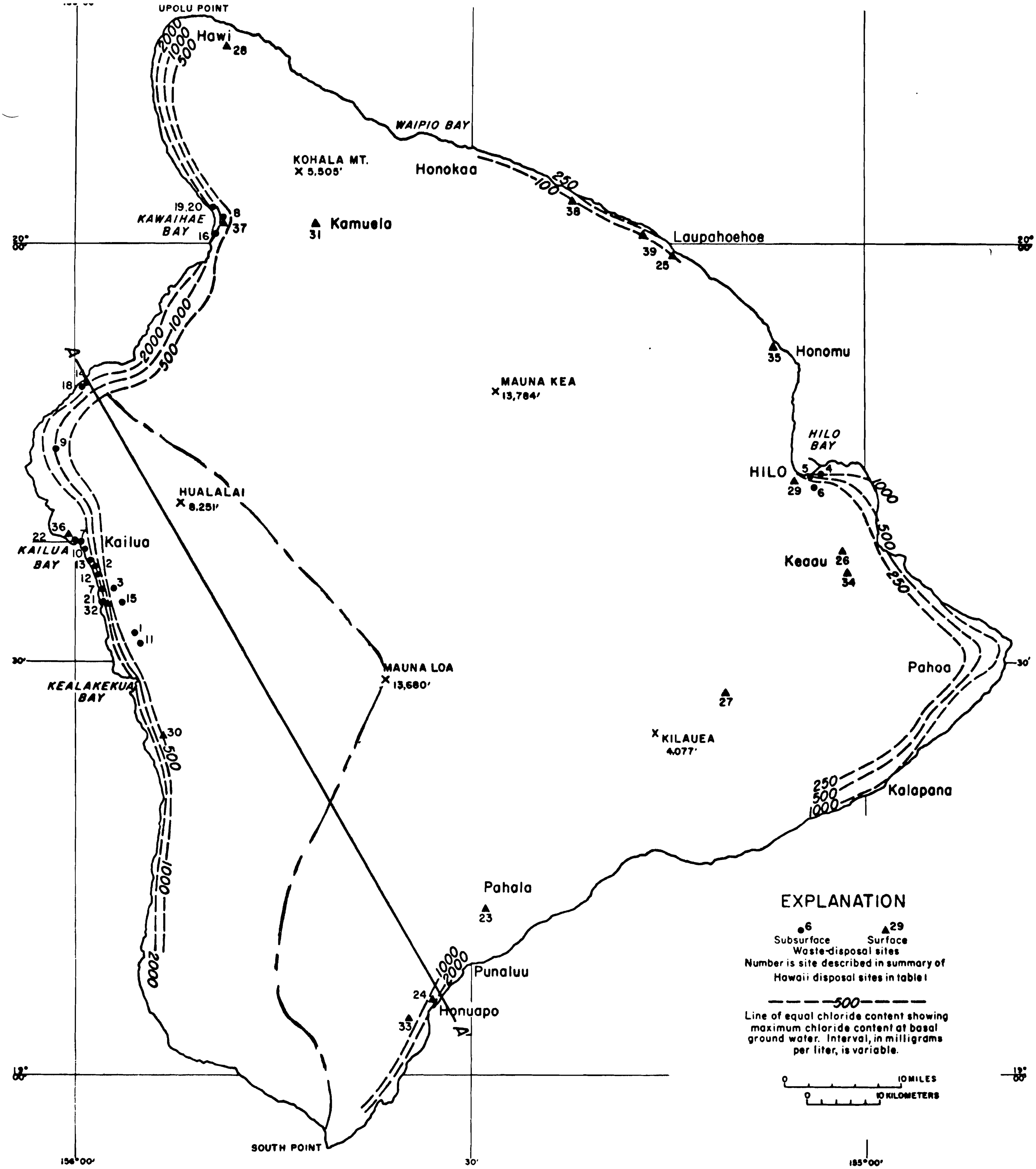


FIGURE 26. MAP OF ISLAND OF HAWAII SHOWING CHLORIDE CONTENT OF GROUND WATER, AREA IV.

Dike-Impounded Water

Dikes deep within the rift zones of Mauna Loa and Hualalai likely impound large quantities of ground water. The depths to water from the surface are also likely to be great.

Perched Water

Ground water may be perched on ash beds or other tight layers interbedded in lava flows, but none appears at the surface. The possibilities of finding large perched supplies are too uncertain to justify extensive exploration.

Present Use of Water

Surface Water

While the flows of Waiaka and Kiilae Streams are quite small, they are valuable sources for domestic and stock supplies.

Ground Water

Basal water is pumped for municipal supply from deep wells near Keauhou and Honaunau. Pumpage in 1973 was about 2 mgd.

Smaller but unknown quantities of brackish to saline water are pumped at shallow wells in the coastal lowlands for watering stock and for other uses.

Potentials for Development

Surface Water

Further surface-water development is probably infeasible. However, supplementing the present water supply by the use of rain catchments may be a possibility.

Ground Water

Basal ground-water flow has been estimated to average about 10 mgd per shoreline mile in the areas fronting wet areas and about 4 mgd per mile in areas fronting dry areas. Owing to the generally high permeability of the lava flows, mixing of fresh water with seawater is prevalent along the entire coast.

A significant part of this recharge, especially in the wet areas, could possibly be recovered from wells drilled 3 or more miles inland from shore, at altitudes in excess of 1,000 feet. Mixing in the dry areas may extend more than 3 miles inland. The minimum depth to fresh water in the dry areas may be well in excess of 1,000 feet generally.

Area V

Geology

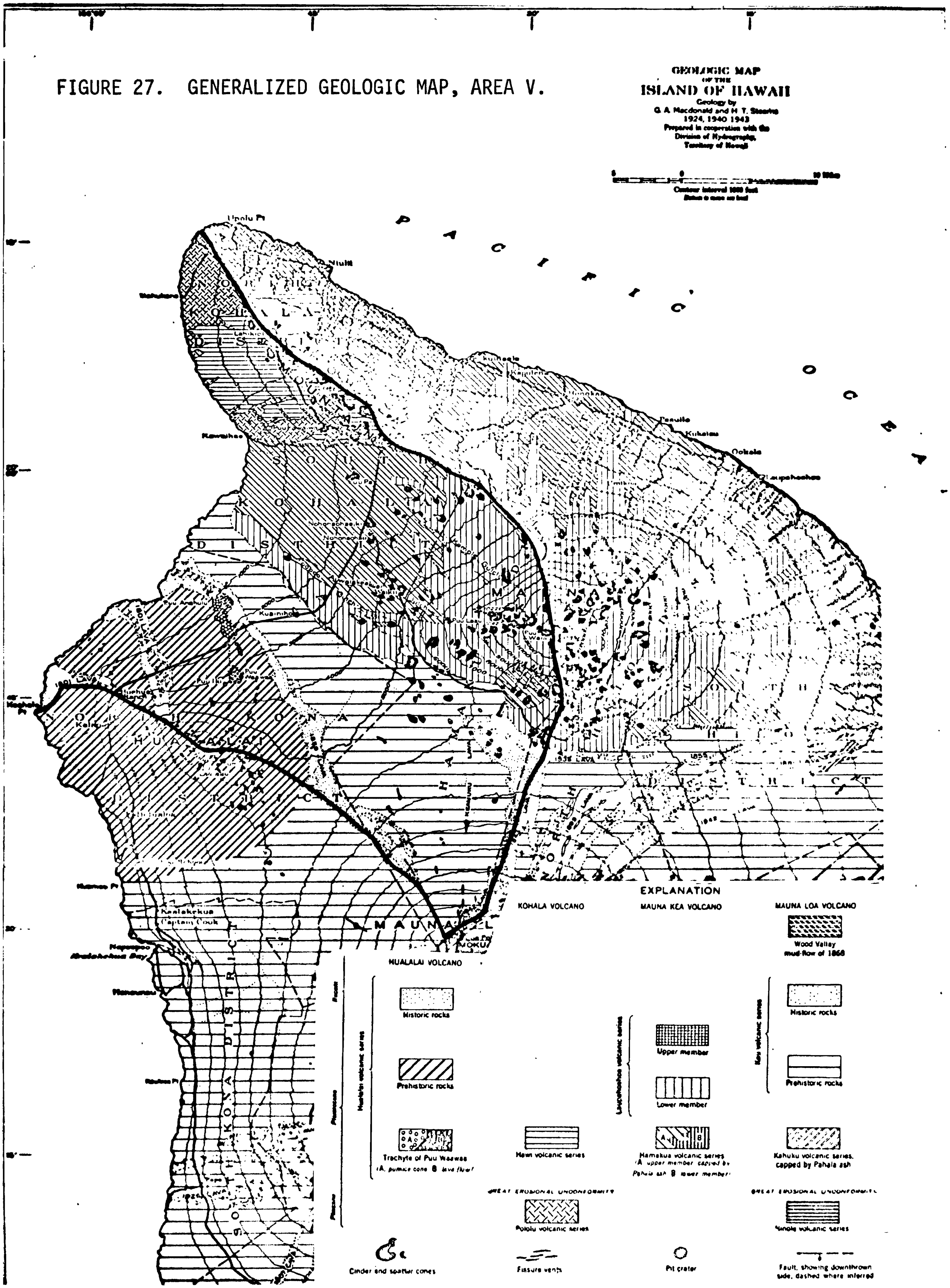
This area of 903 square miles, consists of the southwestern slopes of the Kohala Mountains, the western slopes of Mauna Kea, the northeastern slopes of Hualalai, and the southwestern slopes of Mauna Loa (fig. 27).

The geology, including the sequence of rocks and their water-bearing properties of the area have been discussed in preceding sections (sec. Areas I and IV).

Rainfall

This is the driest of the areas and it receives only about 1,160 mgd of rain a year. Rainfall averages less than 10 inches a year at the leeward shores near Kawaihae, and more than 100 inches a year at the crest of the Kohala Mountains. See figure 28.

FIGURE 27. GENERALIZED GEOLOGIC MAP, AREA V.



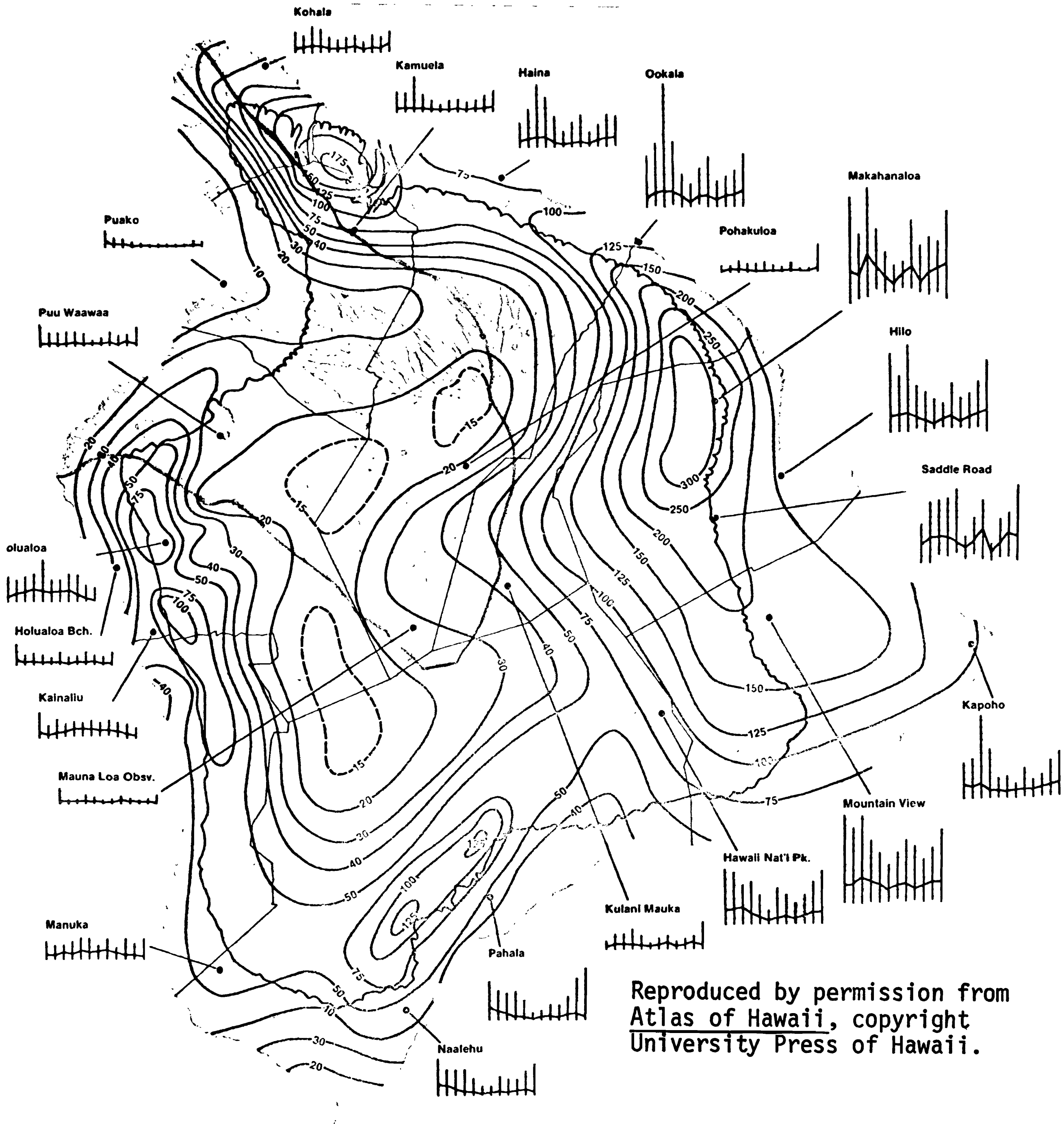
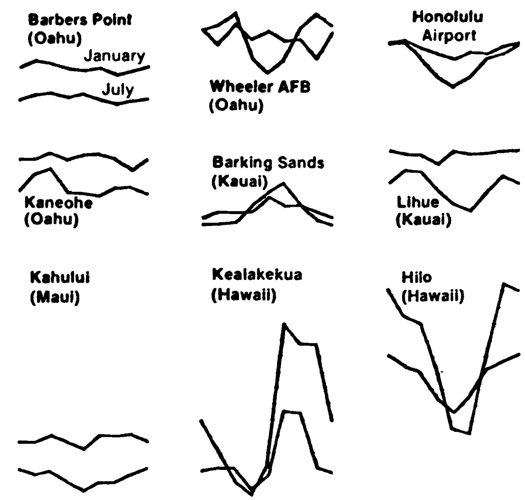


FIGURE 28. AREAL DISTRIBUTION OF RAINFALL.

RAINFALL FREQUENCY BY HOUR OF DAY

Three Hour Intervals Centered at Hour Shown



The diurnal variation in rainfall frequency differs from place to place in Hawaii, since it represents a complex interplay between terrain and wind—both the large-scale flow and the local air movements produced by day-to-night temperature contrasts between land and sea. In places well exposed to the trade winds, showers are usually more frequent during the night and early morning (for example, Lihue in July), reflecting conditions over the open sea or an interaction between the trades and nocturnal offshore land breezes. In contrast, areas sheltered from the trade winds (like Kealakekua, in Hawaii Island's Kona district) tend to have their rainfall maximums in late afternoon and evening, from showers that form within sea breezes which move onshore and upslope during the day.

Although Hawaii has considerably more gages than almost any other area of comparable size, the rainfall of its inaccessible or uninhabited regions remains largely conjectural. Nor is nearly enough known about the effects of smaller terrain features or about contrasts in rainfall between adjoining ridges and valleys.

Surface Water

No perennial streams flow on the slopes of either Hualalai or Mauna Kea.

Streams on the southern slopes of Kohala Mountains originate as outflow from swamps, which are fed by persistent rains. Though they are perennial in their upper reaches, these streams flow into the sea only at times of heavy rainfall. Normally, water, in excess of that diverted for domestic or agricultural use, sinks into the ground miles from the shore. A County of Hawaii system diverts domestic water from Waikoloa, Hauani, and Kohakohau Streams.

Water for irrigation of farmlands in the Waimea area is brought in from the tributaries of Waipio Stream through the Upper Hamakua ditch.

Measured surface water in southern Kohala

	Mgd	
Hauani Stream	1.5	
Keanuiomano Stream	6.0	
Waikoloa Stream	6.0	
Subtotal		13.5

Estimated diversions of surface water in southern Kohala

County system	2.0	
Parker Ranch	0.5	
Subtotal		2.5
Total		16.0

Ground Water

Basal Water

Upolu Point to Kawaihae.--Considerable recharge in the wet summit area of Kohala Mountains moves down to the basal-water body underlying the southern slope. Owing, however, to mixing near the coast, basal water having a chloride content of less than 200 to 300 mg/l probably cannot be found less than 2 or 3 miles from the shore. Basal water discharging at the shore is generally of high salinity.

Much of the discharge of the basal-water body probably is to the south and into Mauna Kea lavas and is discharged to sea in the area south of Kawaihae. Discharge of basal water along the western shores of the Kohala Mountains are apparently significantly less judging by the generally high salinity of the water underlying this coast.

Owing to the generally sporadic rainfall input and to small ground-water storage in thin basal-water lens, much of the discharge of fresh basal water is not recoverable.

The total unused basal-water discharge is estimated at 30 mgd on the basis of the following computations.

	Mgd		Percentage of input	
	Range	Average	Range	Average
Input				
Rainfall --------------		200		100
Output				
Runoff ----------------	70-100	85	35-50	42
Evapotranspiration ----	70-100	85	35-50	42
Surplus to basal ground water -----------	60-0	30	30-0	15

A basal-water body underlying the Waikoloa village area where an exceptionally high basal-water level of 16 feet above mean sea level was discovered 5 miles inland. This high-water level does not conform to lower basal-water levels in the area nearer the coast of 4 and 5 feet above mean sea level. It has been postulated by Dr. Harold Stearns and Mr. Stephen Bowles that a hydrologic barrier exists between the area underlain by the lower water levels and that underlain by the higher.

Dike-Impounded Water

Ground water is probably impounded by dikes under the southern slope of Kohala Mountains, but no valleys are deep enough to tap it. A well was drilled to a depth of 890 feet, or about 1,945 feet above sea level, but did not reach the top of the dike-impounded water body.

Perched Water

Few perched springs flow on the western slope because of low rainfall and because no valleys are deep enough to tap perched-water bodies. Numerous small springs flow from Hawi rocks on the southern slope above Waimea. The springs are too small and too scattered for development.

Present Use of Water

Surface Water

About 3 mgd of surface water is diverted from the streams on the southern slopes of the Kohala Mountains for domestic and stock use.

Parker Ranch diverts about 0.4 mgd from streams on the southern slopes of the Kohala Mountains for stock use on the slopes of Mauna Kea.

Ground Water

Basal water is pumped for golf-course irrigation for Waikoloa village near Kawaihae. Pumpage is probably less than 1 mgd, but pumpage will increase substantially as development in the area continues.

Potentials for Development

Surface Water

A study by Parsons Brinckerhoff-Hirota Associates for the State indicates that a dam on Kohakohau Stream, with an ultimate yield of 10 mgd, all from surface waters, appears feasible.

Upolu Point to Kawaihae.--It is likely that a significant part of the ground-water recharge in the area discharges by underflow to adjacent Mauna Kea lavas to south and thence to sea south of Kawaihae. Because of this, the best area for the development of basal ground water is in the southern part of the area. Basal water underlying coastal areas north of Kawaihae is apt to be brackish, owing to a small ground-water flux per shoreline, high aquifer permeability, and sporadic nature of the rainfall input.

Maui Island Subregion

Geology

The island of Maui, the second largest in the State, with an area of 728 square miles, is composed of two volcanoes, Haleakala (East Maui) and West Maui. The isthmus connecting the volcanoes was formed by lavas from Haleakala banking against the lower slopes of West Maui. Highly permeable basaltic lava flows make up the bulk of the two volcanoes. On Haleakala, the basaltic lavas were almost completely veneered by less permeable andesite in the final stages of mountain building. On West Maui, the basaltic lavas were veneered by andesite and trachyte to a lesser degree. Subsequent deep erosion has exposed much of the basaltic lava flows on West Maui. Much of the deeply eroded valleys of Haleakala were filled with posterosional lava flows, which covered the earlier formed basaltic lavas that were exposed by erosion. The posterosional flows, which are extensive on the eastern and southern flanks of Haleakala, form a highly permeable surface. Posterosional lava flows on West Maui are limited to a small area near Lahaina.

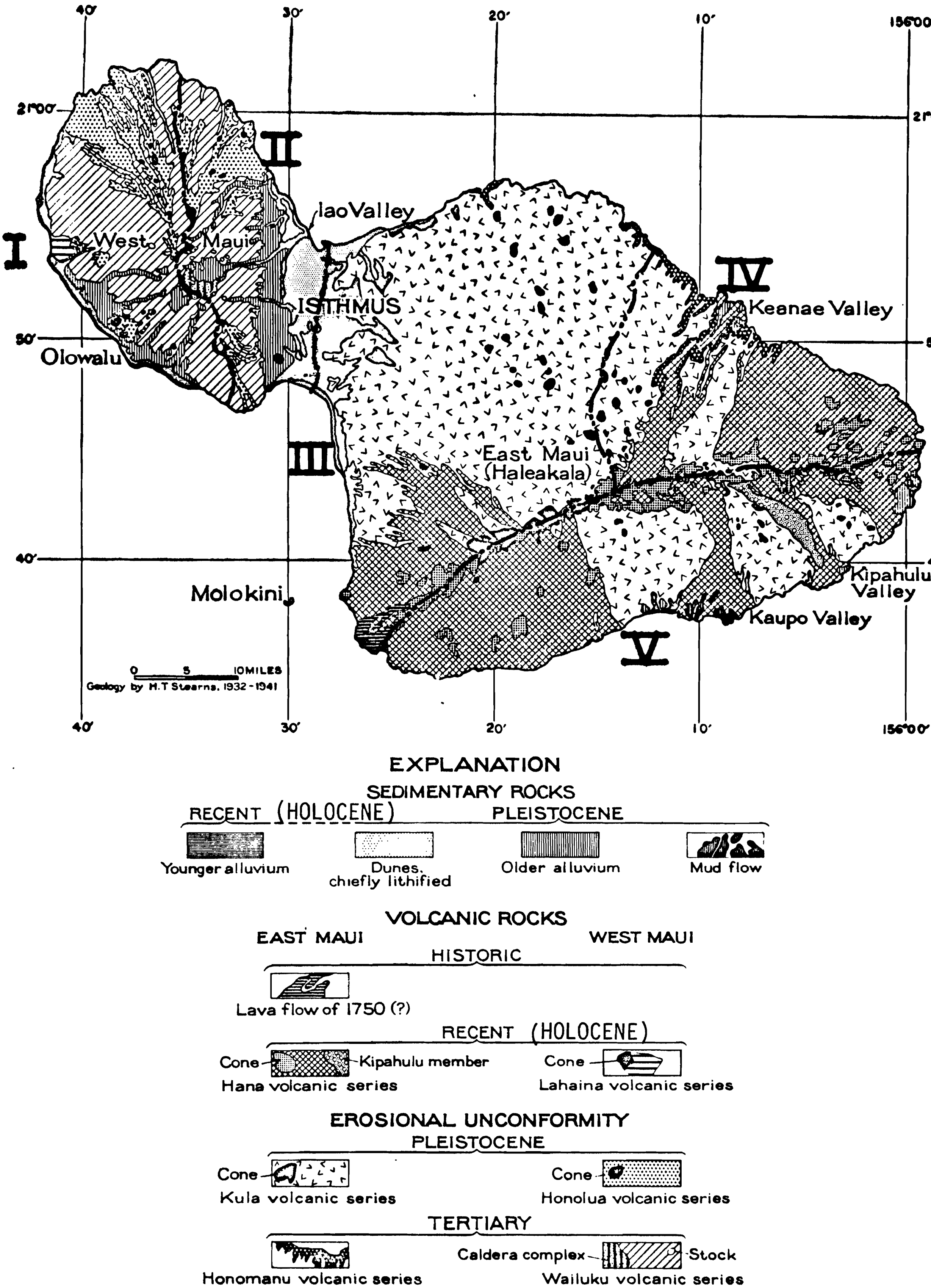
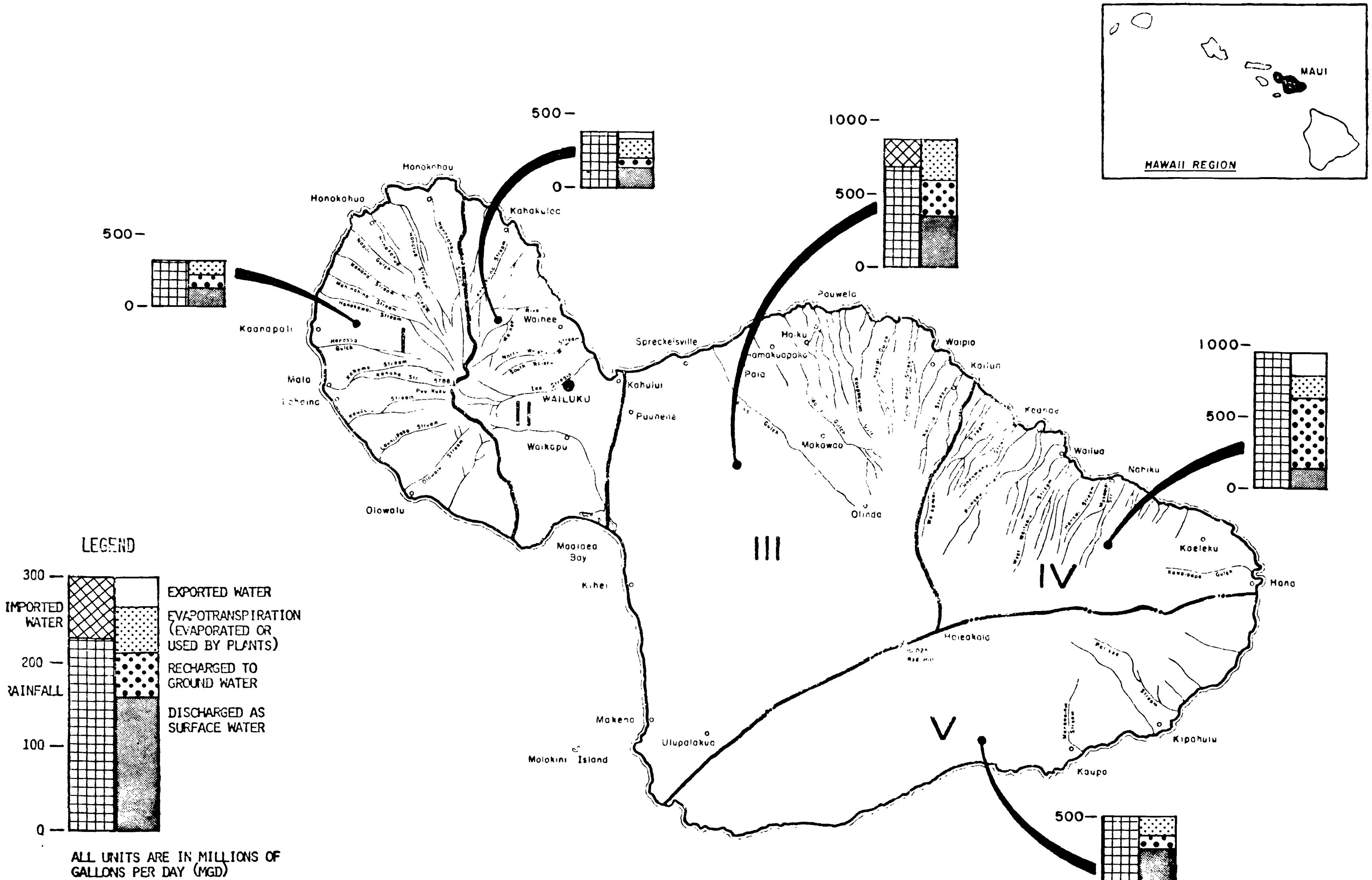


Figure 29. Geologic map of the island of Maui. (After Stearns, 1946.)

Rainfall

Average rainfall is about 80 inches per year, which is equivalent to 2,840 mgd. Haleakala or East Maui, with about 80 percent of the land area, receives about 75 percent of the rainfall. West Maui receives the remaining 25 percent on about 20 percent of the land area. The rainfall in West Maui is symmetrically well distributed with the maximum occurring near the centrally located summit area and the minimum along the coast. In East Maui, the great height and breadth of Haleakala dominate the rainfall pattern, and two-thirds of the rain falls on the lower windward slopes on the northeast side on less than one-third of the land area. The western and southern slopes of Haleakala are virtual deserts in comparison.

A rough accounting of the disposition of rainfall on the island of Maui is shown in figure 30 and table 9. Water developed for irrigation, unless exported out of or imported into an area, is not accounted for. Water used for irrigation, including that of ground water, is combined with evapotranspiration.



SUBREGION 2

ISLAND OF MAUI

FIGURE 30. WATER OCCURRENCE, MAUI.

Table 10. Disposition of rainfall, island of Maui

Island of Maui

(Units in mgd)

Area	Rainfall	Evapotranspiration	Runoff	Ground-water flux
I	340	125	145	70
II	370	130	155[a/]	65
III	685	395[b/]	325	145
IV	925	145	150[c/]	470
V	500	145	270	85

a/ Does not include 20 mgd exported to Area III.

b/ Includes 180 mgd imported from Wailuku and northeast Maui.

c/ Does not include 160 mgd exported to Area III.

Surface Water

Areal Distribution

The areal distribution of streamflow corresponds generally with the areal distribution of rainfall. But the influence of geologic factors is also pronounced. Perennial streams occur in the wet areas of West Maui and in most of the wet areas of East Maui. However, in certain wet areas of East Maui where surface rocks are fresh and extremely permeable, most of the rain sinks into the ground and streamflow occurs only in times of extremely heavy rains.

Leakage from dike-held water bodies sustain low flows of some streams in relatively dry areas of West Maui.

Large quantities of surface water are transported through diversion systems from the wet areas for use in drier areas, mainly for the irrigation of sugarcane.

Runoff into the ocean is estimated to average 300 mgd in West Maui and 755 mgd in East Maui.

Ground Water

Heavy, concentrated pumping of ground water for sugarcane irrigation results in large increases in salinity of the water from wells and shafts each year in the Lahaina area and in the western slopes of Haleakala. The increase in salinity is, however, typically not permanent, and there is usually a comparable annual decrease in the salinity during the months of October to March when pumping is low. In general, there has been no significiant increase in overall salinity of the ground water in areas where the quantity of water imported in by ditches roughly equals the quantity of ground water pumped. In a few of the shafts, especially in East Maui, the water quality has improved considerably in spite of increased pumpage through the years.

In general, ground-water conditions are better in West Maui than in East Maui because of the following reasons:

1. Better rainfall distribution in West Maui.
2. Extensive outcrops of the principal basaltic aquifer in West Maui and almost none in East Maui.
3. Easy access to dike-impounded water sources in the principal aquifer in West Maui and none in East Maui.
4. Shorter distances from ground-water source areas to areas of water need or use in West Maui.

Quality of Water

Surface-Water Quality

Surface water on the island of Maui is characterized by very low dissolved-solids contents and is chemically suitable for most uses. The dissolved-solids concentrations of perennial streams seldom exceed 50 mg/l. Waters in the ephemeral reaches of Iao and Olowalu Streams have higher dissolved-solids contents of 57 mg/l and 151 mg/l, respectively.

Maui's stream waters are very soft, except where they include considerable ground-water contributions. The average hardness concentration is less than 30 mg/l. Hardness at Olowalu Stream ranged from 39 mg/l to 95 mg/l at the lower reaches. At higher reaches, hardness is probably lower.

Chloride in Maui's surface water is due primarily to salt dissolved in rainwater. Most streams have chloride-concentration ranges of 3.7 mg/l to 10 mg/l. Figures 31 through 34 give the ranges and average concentrations of dissolved solids, hardness, chlorides, and silica for selected streams on Maui.

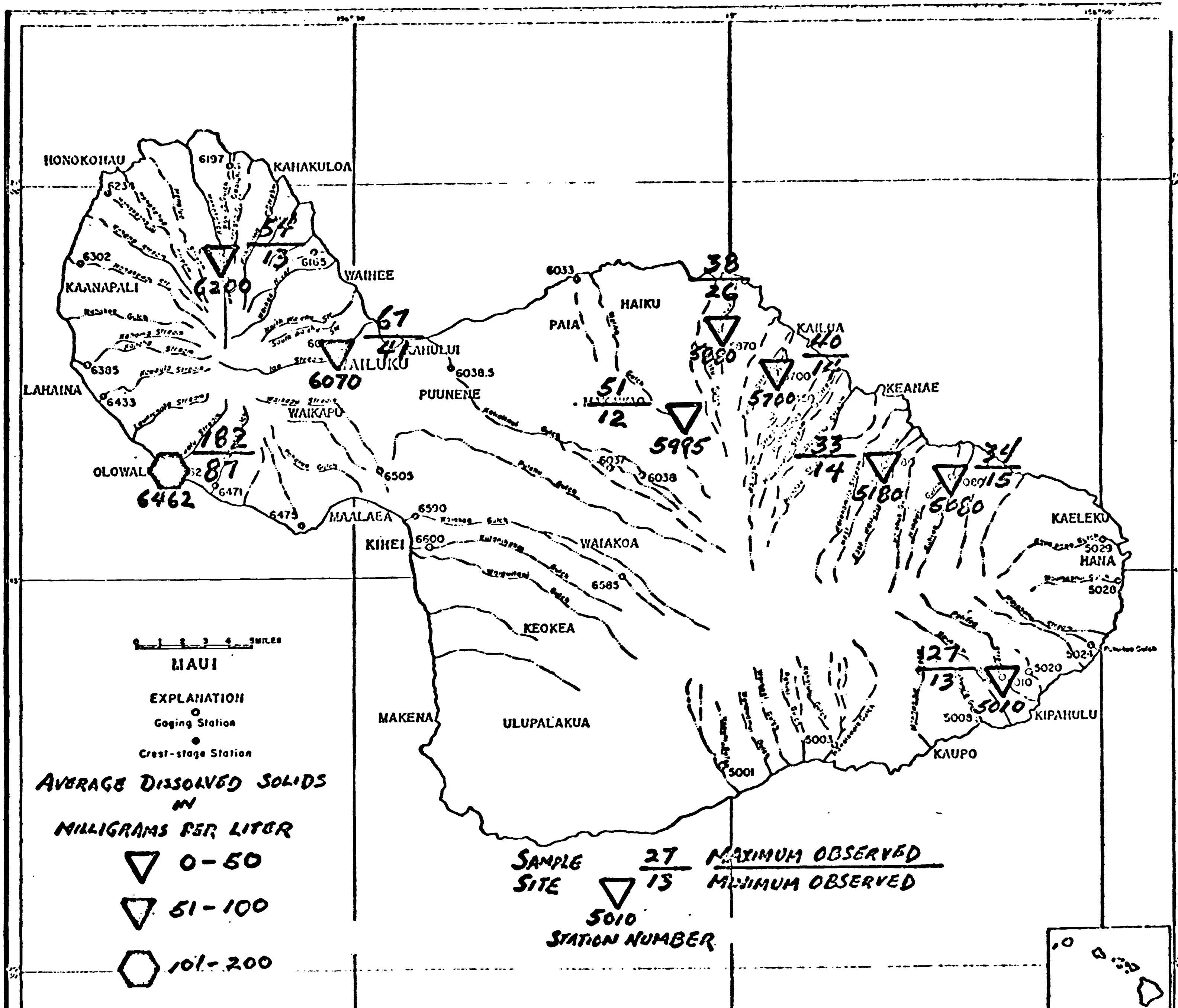


Fig. 31. RANGE AND AVERAGE DISSOLVED-SOLIDS CONCENTRATIONS IN SELECTED STREAMS

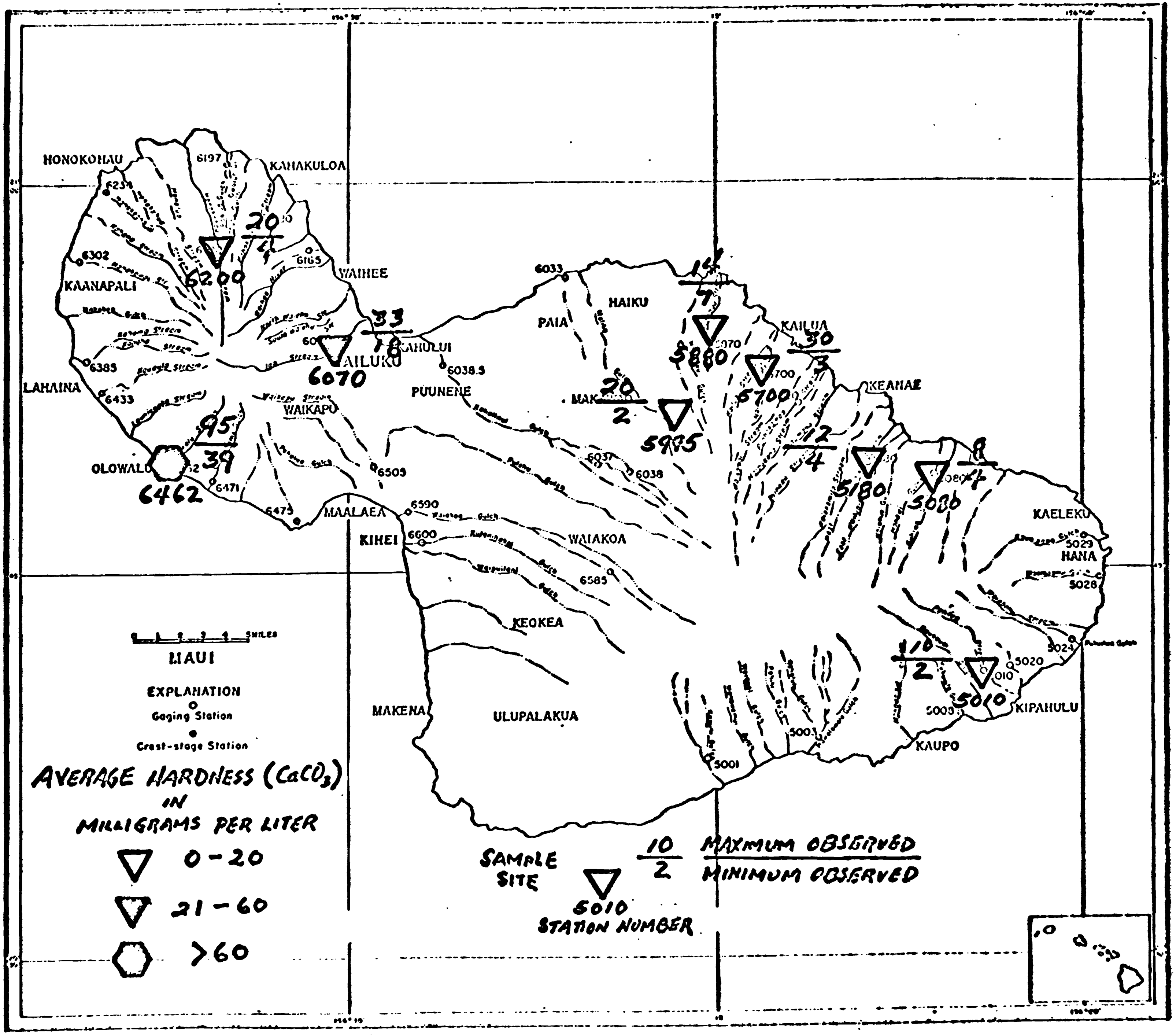


Fig. 32. RANGE AND AVERAGE HARDNESS CONCENTRATIONS IN SELECTED STRE

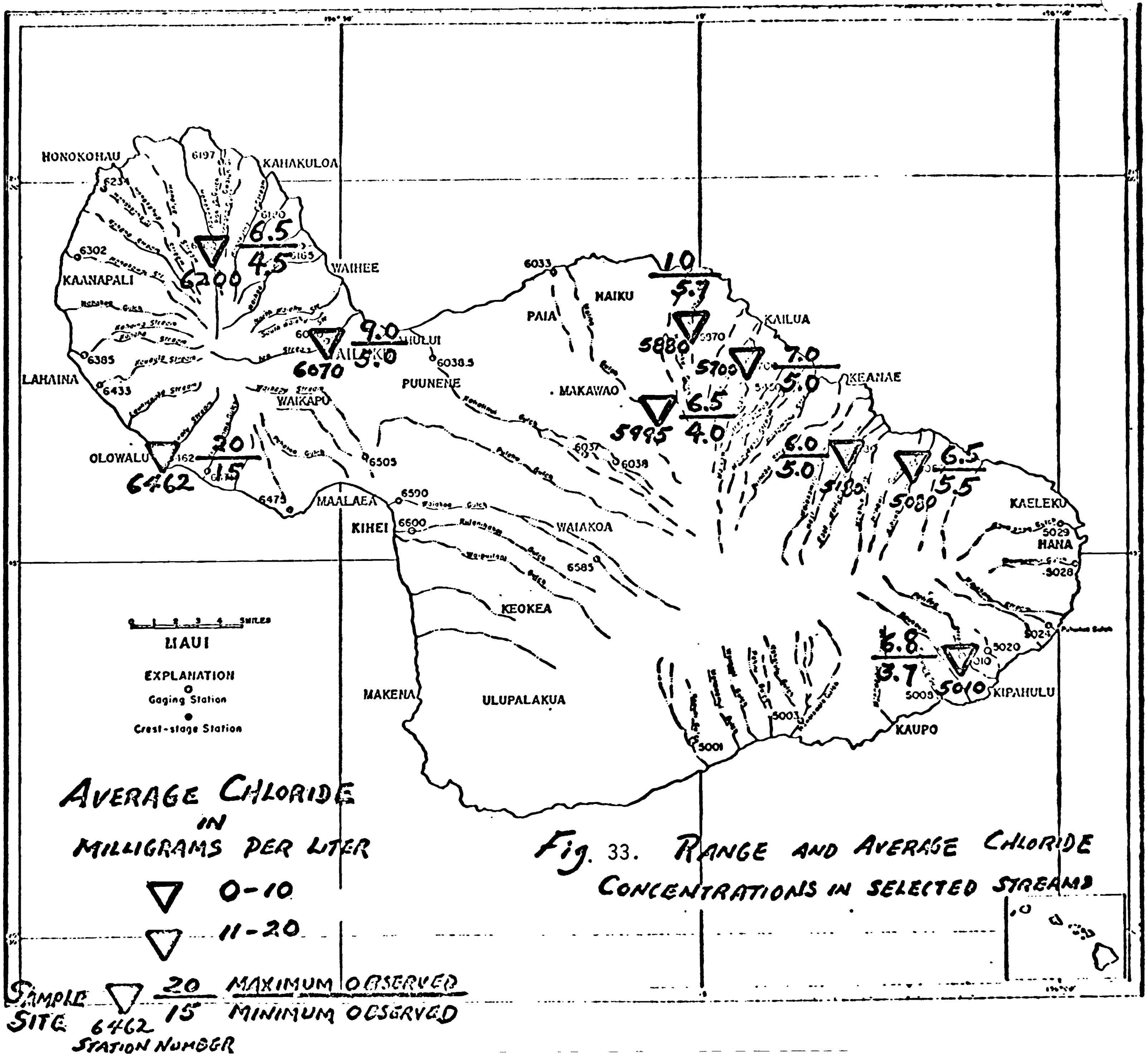


Fig. 33. RANGE AND AVERAGE CHLORIDE CONCENTRATIONS IN SELECTED STREAMS

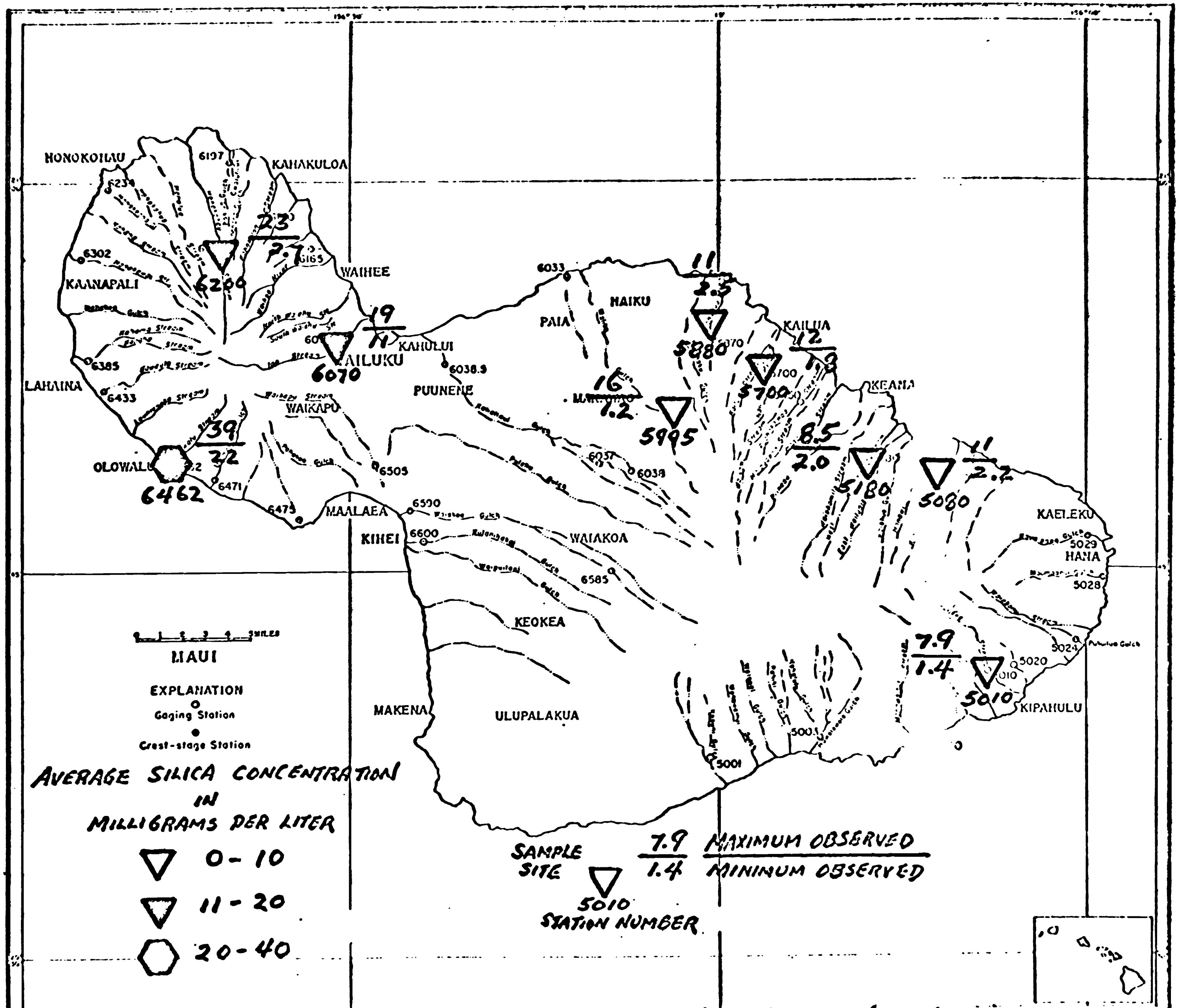


Fig 34. RANGE AND AVERAGE SILICA CONCENTRATIONS IN SELECTED STREAMS

Nutrient contents of surface waters are low. Nitrates and phosphates are seldom detected in stream-water samples.

The physical quality of Maui's surface water is good. Waters in most of the perennial streams have low turbidity. Color concentrations are not high enough to affect either the taste or odor of the water. Stream temperatures range from 16.5^{0} to 20.1^{0}C.

Ground-Water Quality

Maui's basal water is predominantly of the sodium-chloride type, where sodium and chloride amount to more than 50 percent of the dissolved constituents. The quality of the basal water in central and western Maui is highly affected by irrigation practices. Heavy draft during dry periods accelerates seawater intrusion. Conversely, recharge from imported surface water and rainfall freshens the aquifer during nonpumping periods. Many of the coastal wells yield water with dissolved-solids and chloride concentrations that exceed drinking-water standards.

Amounts of bicarbonates in Maui's ground water vary. The highest concentrations are in well waters from the central part of the isthmus. This may be the result of the frequent recycling of irrigation water through calcareous materials in the area.

Concentrations of nitrates in basal water in the isthmus area and near Lahaina range from 5 mg/l to 20 mg/l. These concentrations, while not exceeding drinking-water standards, probably result from irrigation water recharging the basal aquifer.

Good ground water is available in the Kipahulu and Hana areas. Analyses of water from both areas showed dissolved-solids content to be less than 300 mg/l and chloride content less than 100 mg/l. Hardness content is greater than 60 mg/l, and the water is considered moderately hard.

The chemical characteristics of the perched water discharged by springs at various altitudes on northeastern Maui fall generally between the ranges of Maui's surface- and ground-water characteristics.

The different water-quality characteristics in selected streams, springs, and ground-water bodies are summarized in the following table.

Table 11. Summary of different water-quality characteristics in stream, spring, and basal ground water, Maui

Source	Date collected	Dissolved solids (mg/l)	Hardness as calcium carbonate (mg/l)	Chloride (mg/l)	Silicate (mg/l)
Stream water					
West Wailuaiki Stream	Oct. 1973	33	12	6.0	8.5
Hanawi Stream	Oct. 1973	34	8	5.6	11
Palikea Stream	Oct. 1973	27	10	3.7	1.4
Perched water					
Banana Spring	May 1969	156	47	5.0	43
Big Spring	Mar. 1948	166	105	6.7	-
Plunkett Spring	May 1969	118	38	7.0	28
Basal water					
Hana Well 4600-01	Mar. 1972	277	113	78	42
Kipahulu Well 3903-01	Mar. 1972	254	68	106	26

Area I

This area of 96 square miles coincides with that designated as the Lahaina District.

Geology

The rift zones of West Maui are not so well defined as they are in most Hawaiian volcanoes. The dikes generally radiate in all directions from near the summit area. There is, however, a north-south concentration of dikes, which roughly coincides with the boundary separating the Lahaina District from the Wailuku District.

The Lahaina area lies on the west side of a deeply dissected dome called the West Maui Mountain. The bulk of the mountain is made up of thin-bedded, highly permeable, basaltic lava flows of the Wailuku Volcanic Series, the oldest rocks in West Maui. The Wailuku rocks are cut by numerous dikes, many of which are exposed in the walls of the major valleys. The formation of the Wailuku Volcanic Series was followed by a period of weathering, erosion, and deposition. The Wailuku rocks are capped in places by more massive and less permeable andesites and trachytes of the Honolua Volcanic Series. The Wailuku rocks usually are separated from the overlying Honolua rocks by thick soil or by hill wash and stream-laid conglomerates. In other places, the Honolua rocks are absent or lie conformably on the Wailuku rocks.

The distribution of rocks is shown in figure 35 and their sequence and water-bearing properties are given in table 12.

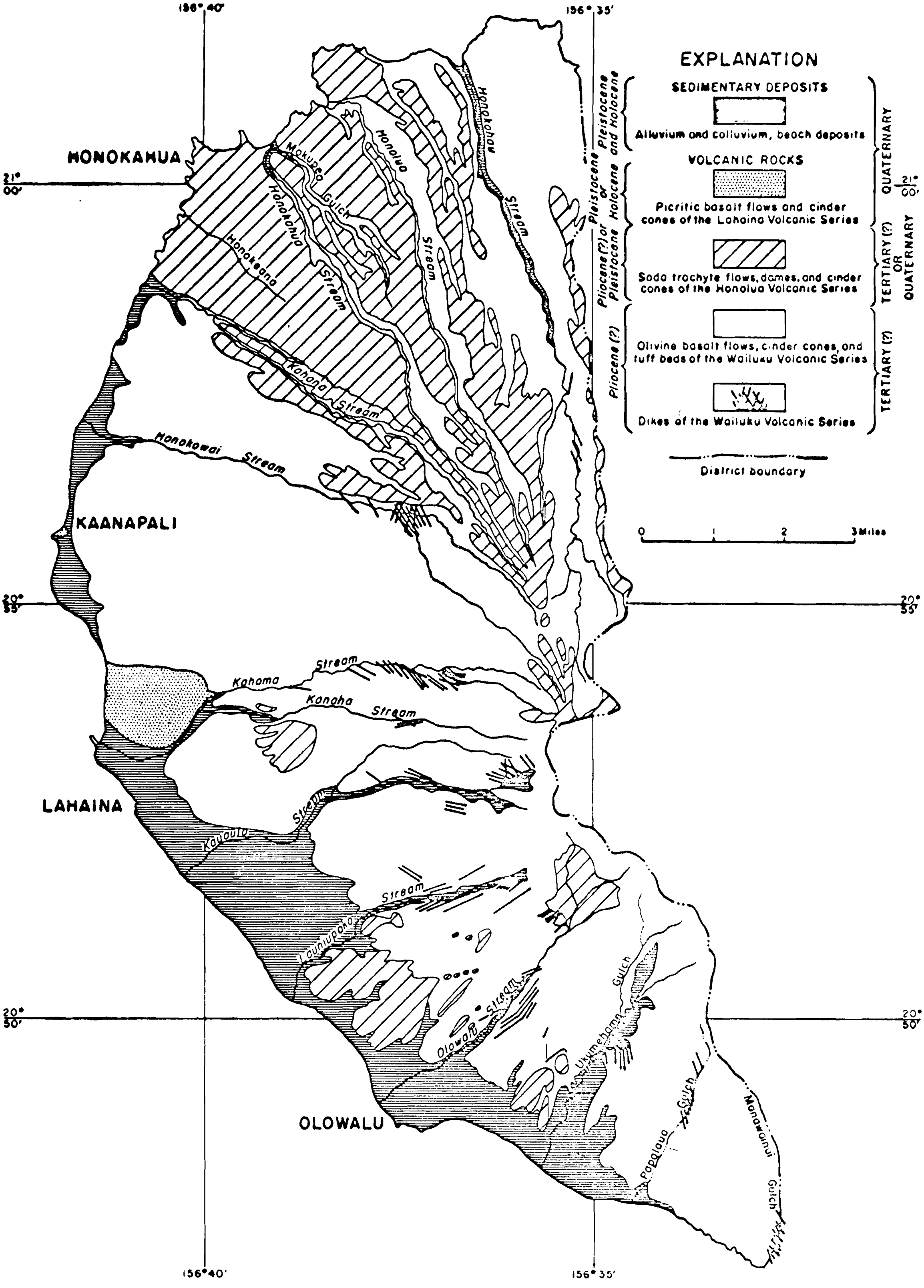


FIGURE 35. GENERALIZED GEOLOGIC MAP, AREA I.

Table 12. GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Geologic unit		Age	Maximum thickness (ft)	Lithology	Water-bearing characteristics
Sedimentary deposits		Pleistocene and Holocene	200+	Unconsolidated beds of alluvial silt, sand, and gravel in stream valleys; beach sand and gravel near the coast. Consolidated rocks consist of dune sand, weathered alluvial conglomerate and colluvium, and cemented alluvial and and marine conglomerate.	Consolidated alluvial, colluvial, dune, and beach deposits are poorly permeable and unimportant as sources of water supply. They may form a caprock in some areas. Unconsolidated beach deposits may yield large amounts of brackish water to wells; unconsolidated alluvium in perennial stream valleys may yield small amount of fresh water to wells.
Volcanic deposits	Lahaina Volcanic Series	Pleistocene or Holocene	150±	Lava flows of picritic basalt and nepheline basanite; cinder and spatter cones.	Small in areal extent and unimportant as a source of fresh water.
	Honolua Volcanic Series	Pliocene(?) or Pleistocene	1,000±	Massive lava flows and domes of soda trachyte; cinder cones; dikes.	Lava flows are massive and thick-bedded and are permeable only along interflow clinker zones; of little value as an aquifer.
	Wailuku Volcanic Series	Pliocene(?)	5,500±	Thin-bedded lava flows of primitive olivine basalt; cinder and spatter cones and thin tuff beds; numerous dikes.	Lava flows consitute the main aquifer and are highly permeable. Yields from skimming tunnels as much as 10 mgd. Pyroclastic deposits are not extensive and are unimportant as aquifers. Thin, impermeable tuff beds in several valleys support perched ground-water bodies that supply small high-level springs. Dikes are dense and of low permeability and retard or divert ground-water movement in the lava beds they cut.

Rainfall

Most of the rain results from rapid cooling of warm, moist trade-wind air, as it is orographically lifted over the West Maui Mountain. Mean annual rainfall ranges from less than 15 inches along the southern shore to more than 400 inches near Puu Kukui (fig. 36). On the basis of this rainfall map, rainfall in the area was computed to average 340 mgd. Most of the rain falls in the mountainous upland where only a few gages are maintained, so this estimate could be considerably in error.

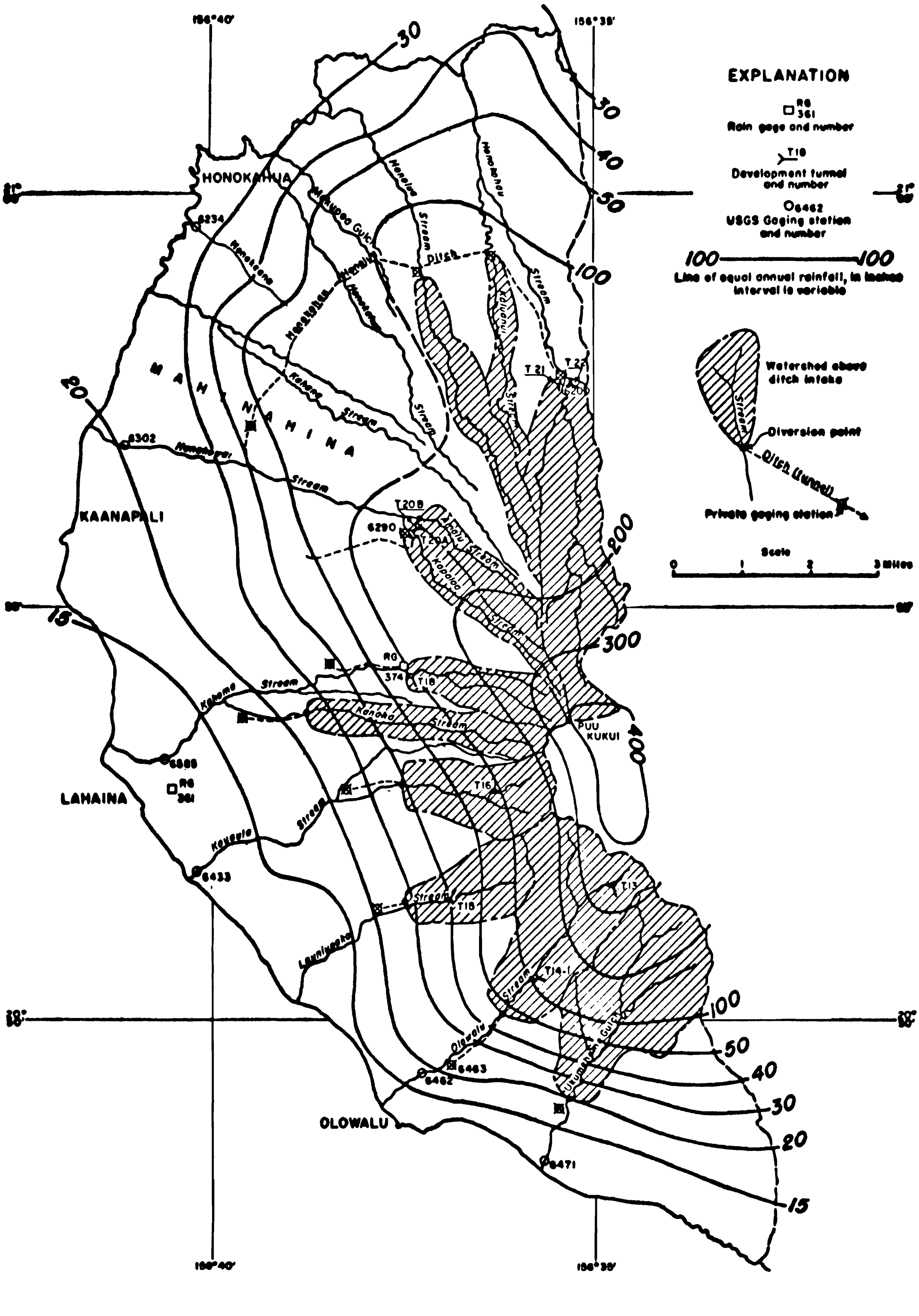


FIGURE 36. AREAL DISTRIBUTION OF RAINFALL, AREA I.

Surface Water

Areal Distribution

Most of the streams in this area are perennial in their upper reaches. However, primarily because of irrigation diversions, only Honokohau Stream approaches continuous flow to the sea.

Streams in the northern half of the area (north of Lahaina) flow in long narrow valleys, which, with the exception of Honokohau Stream, are not very deeply incised. Honokohau Stream, while also long and narrow, has eroded sufficiently that it is, in places, more than 2,000 feet deep. About 26 mgd is diverted and transported to supplement local supplies in meeting the irrigation needs of sugarcane fields in the vicinity of Lahaina.

Valleys south of Kauaula are shorter and wider and streamflow begins in several tributary streams fed by breached dike-held water bodies.

Available information on the streams are summarized in table 13.

Ground Water

Ground water occurs mainly as high-level, dike-impounded water within the upper mountainous area and as basal water in areas seaward of the dike-impounded water. A map of the area showing ground-water sources, ground-water boundaries, and cultivated areas is shown in figure 37.

TABLE 13. MAJOR STREAMS IN AREA 1

Stream	Altitudes of diversion (ft)	Drainage area above intake (sq mi)	Rainfall on drainage area (mgd)	Discharge (mgd)		
				Average flow (estimated)	Average diverted	Minimum
Honokohau	870	4.3	49.8	30	25*	4.3
Honolua	870	1.8	11.8	5	2.8*	0
Honokowai				8	5.7	2.3
Amalu	1,580	1.0	8.6			
Kapaloa	1,550	1.1	12.2			
Kahoma	1,930	1.5	14.4	7	5.2	2
Kanaha	1,140	1.6	7.5	5	2.5	1
Kauaula	1,530	1.9	9.1	7	5.7	5.2
Launiupoko	1,280	1.2	3.7	1	.7	.5
Olowalu	540	3.4	32.0	6	5	3
Ukumehame	240	4.1	19.2	6	4.3	3.1
Total (rounded)		22	168	75	57	23

*Some water diverted for use between Honokohau and delivery point at Mahinahina weir, where average is 25 mgd.

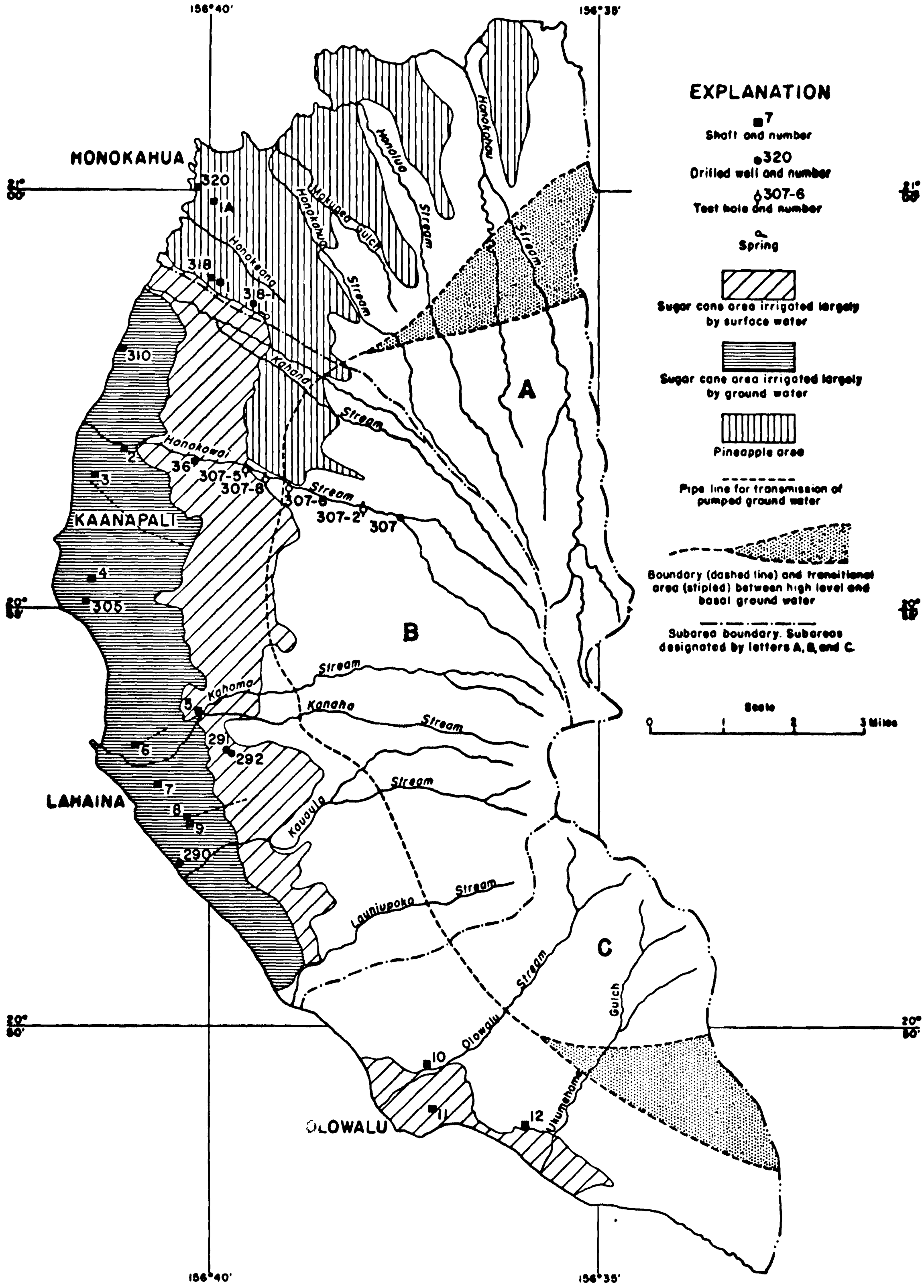


FIGURE 37. GROUND-WATER SOURCES, GROUND-WATER BOUNDARIES, AND CULTIVATED AREAS.

Basal Water

The main body of basal water occurs in dike-free Wailuku basaltic lava flows in all coastal areas and extends inland from 1 to 5 miles. The basal lens is generally thin and the top of it ranges from a few inches to a few feet above sea level. In some areas, such as in transitional areas between basal water and dike-impounded water, the top of the basal lens may be as much as a few tens of feet above sea level. Transitional areas occur where dikes are oriented parallel to ground-water flow. Where dikes are perpendicular to ground-water flow, the boundaries tend to be sharp.

Recharge to the principal basal-water body is by underflow from the upgradient dike-impounded water body and by percolation of rainfall, streamflow, and irrigation water. Discharge is by underflow to sea, by coastal springs, and by pumpage.

The chloride concentration of the water from wells tapping the basal aquifer ranges from 15 mg/l to 15,000 mg/l. Most of the chloride concentrations of the water from basal wells, however, generally fall within the ranges shown by the lines of equal chloride concentration in figure 38. Owing to the absence of extensive low-permeable rocks along the shore, there is free circulation between seawater and the fresh water, and the basal lens is thin and brackish near the coast. Heavy, prolonged concentrated pumping for sugarcane irrigation each year results in large, though temporary, increases in the chloride concentration.

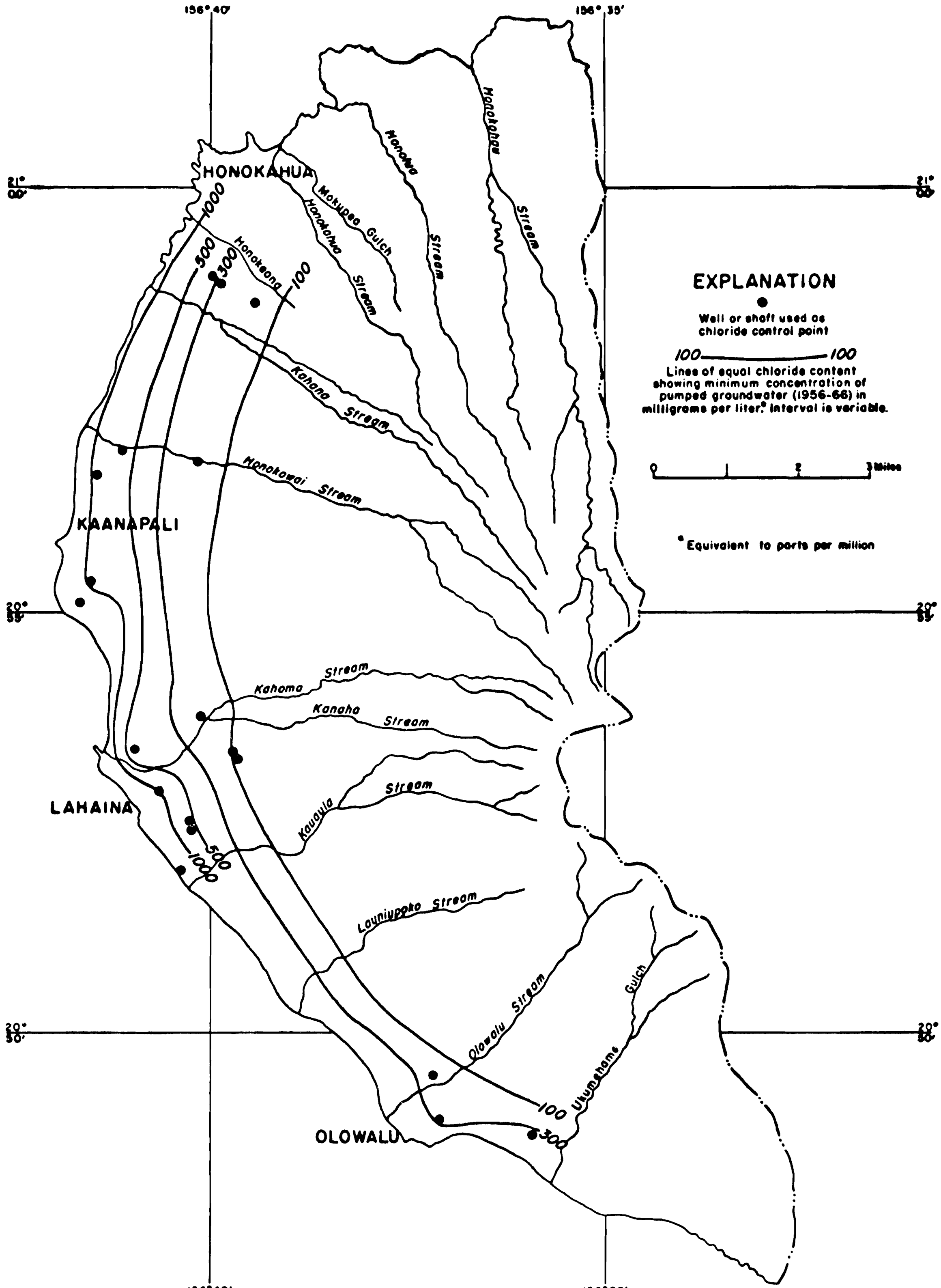


FIGURE 38. LINES OF EQUAL CHLORIDE CONTENT, AREA I.

Dike-Impounded Water

Ground water is impounded by dikes far above sea level. Dike-impounded ground water occurs in an oval-shaped area underlying the central part of the West Maui Mountain (fig. 37).

Heavy rainfall in the upland areas recharges the dike-impounded reservoir. Dike-impounded water discharges from springs and seeps emanating from dikes breached by streams and by underflow. The quality of water impounded by dikes is excellent.

Present Use of Water

Present water needs for the area are met by a number of systems, privately or publicly owned. The Maui County Department of Water Supply has four separate domestic water systems. Amfac, Inc. has an irrigation system and a domestic system for the Kaanapali area; Maui Land and Pineapple Co. provides water for its needs and Pioneer Mill needs, and also makes water available for the County Department of Water Supply for domestic purposes. These systems provide aproximately 100 mgd, of which 95 mgd is for irrigation, 2 mgd for domestic purposes, and 3 mgd for industrial and other miscellaneous purposes.

Most of the irrigation water developed is for sugarcane and is mainly developed in four ways: (1) diversion of streamflow within subareas B and C (fig. 37), (2) diversion of streamflow from subarea A to subarea B through Honokohau ditch, (3) diversion of dike-impounded high-level water by tunnels, and (4) pumping basal ground water in subareas B and C.

Surface Water

As shown in table 13, about 57 mgd of surface water is now being diverted for irrigation and domestic use. This amount includes all the low flow available in the streams above the various diversion points. Some additional flow arises in Honokohau Stream below the diversion point, but this water is needed for taro lands in the lower end of the valley. A wasteway gate on Honokohau ditch supplies additional water for the taro lands when needed.

Ground Water

Of the approximately 100 mgd of water developed by the water systems, about 50 mgd is ground water, which is pumped from the main basal-water body. Of the basal ground water pumped, about 45 mgd is used for sugarcane irrigation, about 3 mgd for industrial and other miscellaneous use, and about 2 mgd for domestic use. Development of dike-impounded water is by means of free-flowing tunnels. About 10 mgd of dike-impounded water is developed by this means and diverted to ditches for sugarcane irrigation.

Potentials for Development

The conclusions and recommendations by Belt, Collins and Associates, Ltd. in their report to the State entitled, "A Water Source Development Plan for Lahaina District," were based largely from a water-resources picture, which unfolded from their water-budget analysis. Many of the parameters used were not known but the budget approach appears to be the best device for the establishment of overall order-of-magnitude values. The end result of the budget analysis was keyed to determine the amount of exploitation of ground water that can take place. To relate resource availability to needs, the years were analyzed in two separate periods--April through October and November through March. The area was divided into three subareas which coincide with the subareas shown in figure 37. The report was published as Report R33 for the State Division of Water and Land Development.

Ground Water

The following table represents a summation of the water budgets developed by Belt, Collins and Associates, Ltd. The value under "Surplus Ground-Water Flux" is taken as the net amount of water available to recharge the aquifer under prevailing median rainfall conditions.

The following comments relating to the water budgets were extracted from the report by Belt, Collins and Associates, Ltd.

Subarea A.--The entire 29-mgd figure for surplus ground-water flux cannot be taken for use in the area because of the following two reasons. First, this figure is based on a median monthly value, which means that 50 percent of the time the amount of water going to ground-water recharge is less than 29 mgd. Limited studies indicate ground-water recharge is of an order of magnitude of one-third the median year value. Secondly, a large portion of the flow of ground water is required merely to maintain the fresh-water integrity of the basal-water lens.

Subarea B.--Budget was developed by E. W. Broadbent of Amfac, Inc. Same basic approach was applied in developing the budget.

Subarea C.--The chloride concentration of the water from development shaft is markedly responsive to water levels and, thus, highly dependent on ground-water recharge. Owing to the low-surplus figure of 6 mgd, future development of major water supplies in this Subarea is very doubtful.

Table 14. Water Budget (a)

Sub-area	Gross rain-fall	Irrigation evapo-transpiration	Net effective rain-fall	Runoff	Natural rain-fall surplus	Ground to water consumptive use	Domestic, industrial, and other use	Surplus ground-water flux	Source of information
A	112	49	73	40(b)	33	4	-	29	Belt, Collins and Assoc.
B	112(c)	54	58	17	41	-	5	35	Amfac, Inc.(d)
C	40	22	15	9	6	-	-	6	Belt, Collins and Assoc.

(a) Rainfall computed from isohyetal map, which represents a summation of monthly median rainfall for two separate rainfall periods--April through October and November through March.
(b) 24 mgd of runoff figure is water exported to Subarea B.
(c) 24 mgd of gross rainfall figure is water imported from Subarea A.
(d) Broadbent, E. W., 1969, An estimate of present and future sources of water in the Lahaina-Kahana sector of West Maui: a report for Amfac, Inc., November 7, 1969.

Area II

This area, of about 75 square miles, is mainly the part of the Wailuku District which lies in West Maui. The eastern part is not included.

Geology

The area lies on the east side of the deeply dissected dome of the West Maui Mountain. The oldest rocks are basalts of the Wailuku Volcanic Series, which form the bulk of the dome. Flows of andesite and trachyte of the Honolua Volcanic Series, which followed and covered much of the dome, are present on the northern slopes but are absent on the eastern slope. This initial mountain-building phase was followed by a long period of quiescence, during which time valleys were deeply incised. Stream cutting subsequently ended and a period of deposition followed, which resulted in alluvium-filling valleys and mantling the lower slopes of the dome up to about an altitude of 1,000 feet. This period of deposition may have been contemporaneous with the ponding of Haleakala lavas against the eastern slope of the West Maui dome. Rocks of the latest volcanic activity, the Lahaina Volcanic Series, are limited in this area to a small cinder cone near Maalaea.

The principal aquifer consists of thin-bedded flows of the Wailuku Volcanic Series. These highly permeable rocks are cut by numerous dikes. The Honolua andesite and trachytes are less permeable than the Wailuku basalts, and wherever they overlie Wailuku basalts, they generally inhibit recharge to ground-water bodies. The older alluvium, which filled the deeply cut valleys and mantled the lower slopes, are highly impermeable and carry little water. It extends several hundred feet below sea level in places, and forms a deterrent to ground-water flow in the principal aquifer across deep valleys and eastward toward Haleakala.

The areal distribution of rocks in the area is shown in figure 39.

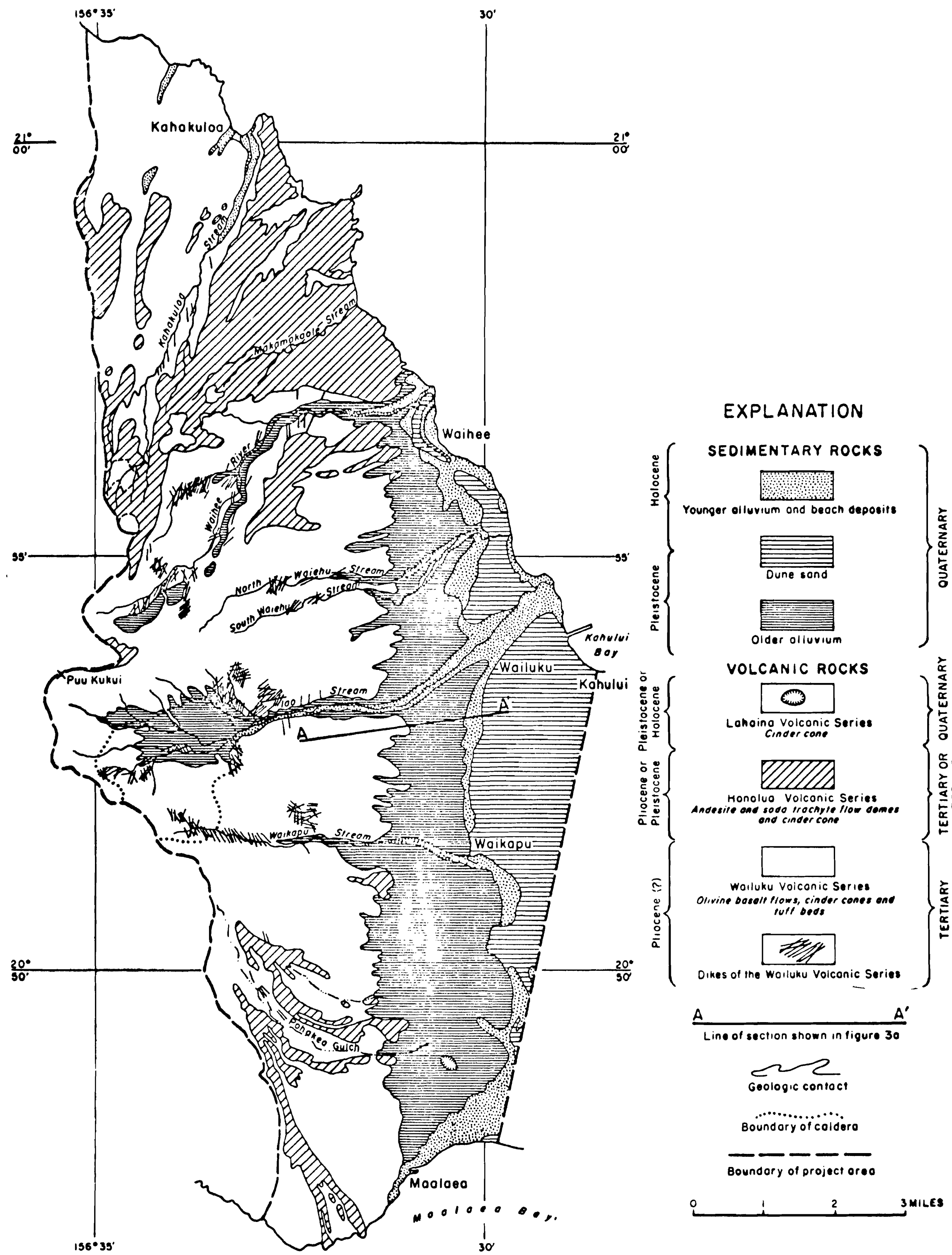


FIGURE 39. GENERALIZED GEOLOGIC MAP, AREA II.

Rainfall

Most of the rain results from rapid cooling of warm, moist trade-wind air, as it is orographically lifted. Trade-wind rainfall is heaviest near the crest and decreases rapidly downslope. Mean annual rainfall ranges from less than 15 inches near Maalaea to about 400 inches per year near Puu Kukui. The rainfall map (fig. 40) was taken from a National Weather Service map prepared in 1955.

The rainfall for the area can only be estimated roughly because there are only a few gages in the rainy, remote, rugged, mountainous uplands. On the basis of the rainfall map, the total rainfall is estimated to be about 370 mgd. Most of the rain falls in the mountainous upland, so this estimate based on few gages in the rainier areas may be considerably in error.

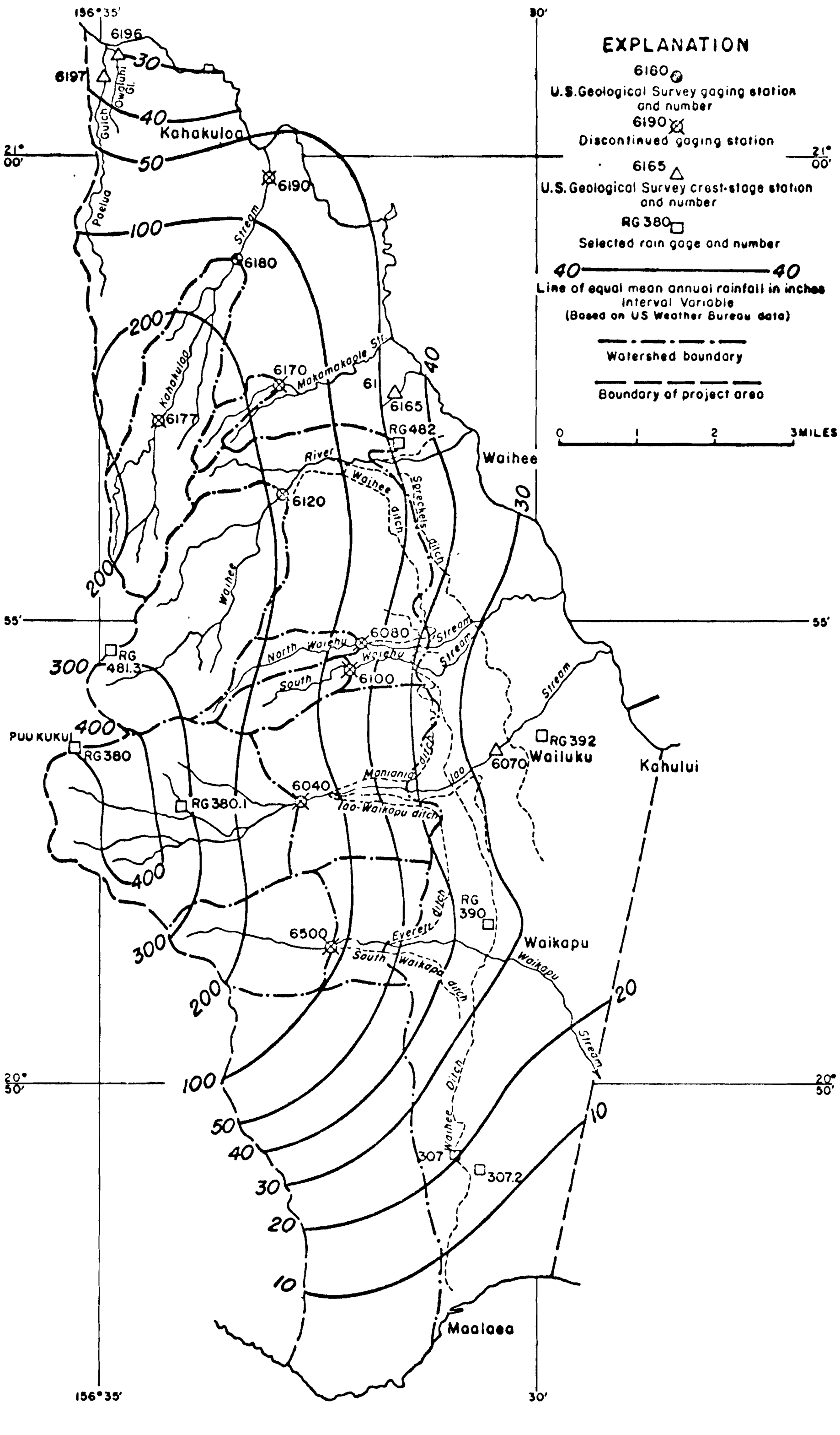


FIGURE 40. MAP SHOWING DISTRIBUTION OF MEAN ANNUAL RAINFALL, AREA II.

Surface Water

Perennial streams in this area occur only north of Waikapu Valley, as rainfall southward is insufficient to maintain streamflows except during storms. Erosion in the wet mid-section of the area has created the large valleys of Waikapu, Iao, and Waihee. The headwaters of south and north Waiehu streams and gulches in this area have been truncated by the more rapid erosion in Iao and Waihee watersheds.

Base flows of the streams between and including Waikapu and Waihee are maintained chiefly by leakage from dike-held high-water bodies. Except for water maintained, expressly because of prior rights for irrigation of taro lands, in the lower reaches of Waiehu and Waihee Streams, all the dry-weather flow of these streams is being diverted for the irrigation of sugarcane. Consequently, the streambeds of both Waikapu and Iao Streams are dry in their lower reaches.

Makamakaole Stream, north of Waihee, is a small perennial stream which derives its base flow mainly from springs fed by water perched on weathered clinker beds and dense lava flows.

Base flow of Kahakuloa Stream, in the extreme north end of this area, is evidently maintained by water draining from swampy lands near Eke Crater. The stream itself flows with a gentle gradient in a long, narrow valley. Water flows perennially to sea after satisfying the needs of taro plantings in the lower sections of the valley.

Available information on the streams in this area are summarized in the following table.

Ground Water

Ground water in the area occurs as basal water, as dike-impounded water, and as perched water. A map showing ground-water sources, ground-water boundaries, water levels, and chloride concentration is shown in figure 41.

Annual Rainfall and Runoff Data for

Selected Watershed Areas in Wailuku Area

Watershed	Altitude of measuring site (ft above msl)	Area of watershed above measuring site (sq mi)	Rainfall on area (mgd)	Runoff from area (mgd)	Amount diverted and used (mgd)
Waikapu	880	2.2	19	10	3
Iao	860	5.4	77	50	18+[a]
South Waiehu	870	.87	6	5	3
North Waiehu	880	.85	7	5	3
Waihee	620	4.2	54	50	40
Makamakaole	1,500	.42	4	2	(b)
Kahakuloa	330	3.3	37	11	(c)
Total (rounded)		17	204	133	

a Some additional water diverted during high flows not included.

b Small amount diverted for stock use.

c Undetermined amount diverted for taro irrigation.

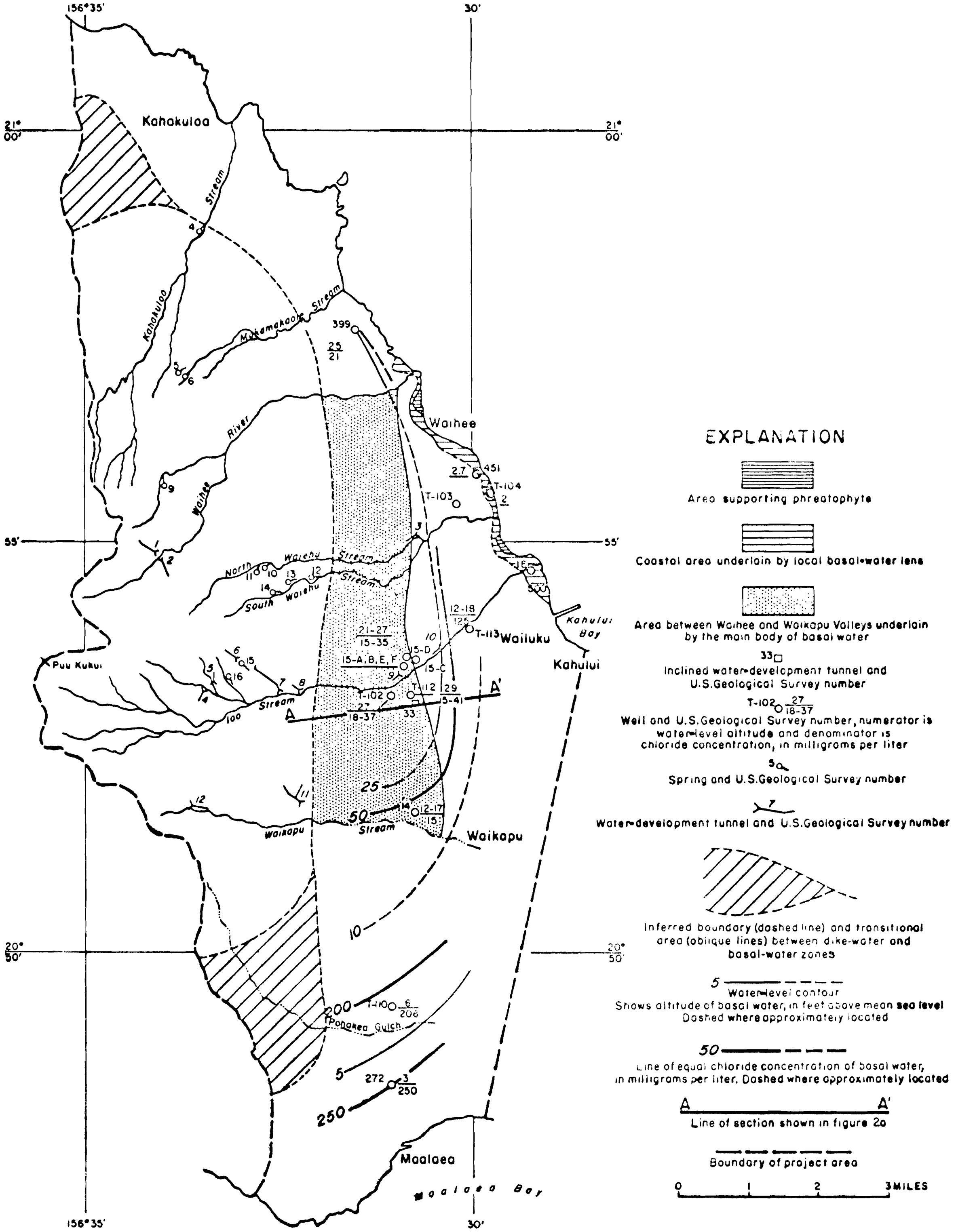


FIGURE 41. MAP SHOWING GROUND-WATER SOURCES, GROUND-WATER BOUNDARIES, WATER LEVELS, AND CHLORIDE CONCENTRATION, AREA II.

Basal Water

The highly permeable basaltic lava flows of the Wailuku Volcanic Series form the reservoir for the main body of basal water. Locally, small basal-water bodies occur in younger alluvium and dune-sand deposits. A sizeable basal-water body, recharged mostly by rains and irrigation-water return in West Maui, occurs in Haleakala lava flows underlying the isthmus.

The boundary between basal water and dike-impounded water may be sharp or transitional, depending on how the dikes are oriented relative to the flow of ground water. Where the dikes are perpendicular to ground-water flow, the boundaries tend to be sharp, otherwise they may be transitional. The boundary may be transitional in the areas south of Waikapu Valley and west of Kahakuloa Valley.

Water levels in the principal basal-water body ranges in altitude from less than 3 feet to about 30 feet (fig. 41). The highest water levels occur between Waikapu and Waihee Valleys. Flow of basal water to the east is impeded by a thick wedge of older alluvium, which extends from Waihee Valley to Maalaea.

Recharge to the principal basal-water body is by underflow from the dike-impounded water body, by direct percolation of rainfall and irrigation water. Discharge is by underflow beneath or around the older alluvium barrier, and by pumpage.

The following table was prepared by Melvin C. Caskey for his master's thesis submitted to the graduate division of the University of Hawaii in 1968. Caskey considered only that part of the basal aquifer from Iao Valley to Maalaea, which he called the Waikapu aquifer. The table was prepared by quantifying elements of the following hydrologic mass-balance equation.

$$G_b = G_h + P_b + I_r - E_b - D_b$$

where

G_b = 28.4 mgd = ground-water discharge from Waikapu aquifer

G_h = 16.7 mgd = ground-water transfer from dike-impounded aquifer

P_b = 4.3 mgd = precipitation over Waikapu aquifer

I_r = 19.2 mgd = irrigation-water return

E_b = 7.4 mgd = evapotranspiration over Waikapu aquifer

D_b = 4.4 mgd = draft upon Waikapu aquifer.

The right-hand side of this equation represents the net recharge to the Waikapu aquifer.

Recharge of the Waikapu basal aquifer

(From Melvin C. Caskey, 1968, "The recharge of the Waikapu aquifer, Maui")

Source	Minimum estimate (mgd)	Average estimate (mgd)
Transfer from high level aquifers		
Iao Valley	0.8	16.2
Between Iao and Waikapu Valleys	0.2	0.3
Waikapu Valley	0.0	0.0
South of Waikapu Valley	0.0	0.0
Total	1.0	16.7
Direct recharge		
Unirrigated areas	0.2	0.3
Irrigated areas	14.0	15.8
Total	14.2	16.1
Total recharge	15.2	32.8
Draft upon aquifer	4.4	4.4
Net recharge	10.8	28.4

The average rainfall in the wet mountainous area from Iao Valley to Waihee Valley is about 40 percent higher than it is from Iao Valley to Maalaea. The geology, both on the surface and in the subsurface, is similar, so recharge characteristics are likely similar with recharge to ground water, dependent only upon the quantity of rainfall. If Caskey's figure of approximately 17 mgd of transfer from the high-level aquifer is used, then the recharge and subsequent transfer from the high aquifer from Iao Valley to Waihee Valley should approximate 24 mgd. On the other hand, irrigated areas between Iao Valley to Maalaea is about twice that from Iao Valley to Waihee Valley. Using Caskey's figure, the direct recharge from irrigation water should be only half as much from Iao Valley to Waihee Valley, or 8 mgd. The recharge to the basal aquifer from Iao Valley to Waihee Valley is then approximately 32 mgd. The draft upon the aquifer is about 5 mgd, making the net recharge approximately 27 mgd.

The average rainfall in the mountainous areas from Waihee Valley to the north boundary is about half of that from Iao Valley to Waihee Valley. The surface geology is different in that the older alluvium, which forms an apron in the lower slopes of the other areas, is absent and much of the higher slopes are covered by lavas of the Honolua Volcanic Series. Because of the lesser rainfall and the cover of lowly permeable Honolua rock in much of the area, recharge to the basal-water body is estimated at 5 to 10 mgd. There are no irrigated sugarcane areas, hence, no contribution to the basal-water body from irrigation-water return.

In summary, recharge to the basal-water body comes from the underflow of dike-impounded water and direct rainfall recharge. This quantity, which is estimated at 45 mgd, represents about 20 percent of the rainfall in and out of the area underlain by dike-impounded water. About 24 mgd of recharge is derived from irrigation-water return. This figure represents about 50 percent of the water applied for irrigation.

Dike-Impounded Water

Dike-impounded ground water occurs in an oval-shaped area underlying the central part of the mountain owing to a radial dike pattern in the West Maui Mountain (fig. 41). Dike-impounded water discharges from springs and seeps in deeply-cut valleys and contributes to base flow of streams from development tunnels, and by underflow through or over the dikes. The average visible discharge of dike-impounded water in the area was estimated to be about 47 mgd by Harold T. Stearns (1942).

Perched Water

Perched ground water occurs in the younger alluvial sand of Iao and Waihee Valleys and in the consolidated dune sand between Waihee and Wailuku. Perched-water bodies are generally small. They are recharged by rainfall and by streamflow seepage in stream channels and by rainfall and seepage from irrigated sugarcane field.

Stearns and Macdonald (1942) note that Makamakaole Stream heads in two springs, which issue from clinker beds probably perched on weathered clinker and dense trachyte.

Present Use of Water

Surface Water

As shown in the table on page 168, the low and medium flows of all streams except Makamakaole and Kahakuloa are now being diverted. Some water is diverted for stock use from Makamakaole Stream and for taro cultivation from Kahakuloa Stream.

Ground Water

Most ground water developed is used for the irrigation of sugarcane. Development of dike-impounded high-level source consists mainly of diverting discharge from water-development tunnels and major springs to irrigation ditches. The discharge of springs averages about 5 mgd and that from tunnels about 9 mgd. About 2 mgd of the flow of dike-impounded water is diverted by a water-development tunnel for municipal use.

An average of about 5 mgd is pumped from the principal basal-water aquifer in the Wailuku area for the irrigation of sugarcane. Pumpage on a daily basis ranges from zero to more than 12 mgd. Pump capacity of this installation, which consists of a battery of three wells drilled in a water-development shaft, is 15 mgd but is soon to be increased to 22 mgd.

A battery of three wells in the north bank of Iao Stream supplies domestic water to Wailuku and Kahului, Paia, Kihei, and Maalaea in East Maui. These wells, known as the Mokuhau battery, are pumped at an average rate of about 5 mgd, but have a combined capacity of about 12 mgd. Pumpage from the Mokuhau battery is fairly steady throughout the year unlike the battery of wells, which supplies irrigation water.

So far, pumping has had little effect on the chloride concentration of the water from the main basal-water body.

Except for a small but unknown number of shallow, low-yielding wells used for lawn and garden irrigation, there is little development of the thin basal lens along the coast. The water pumped from these wells is generally brackish, and the possibility of obtaining satisfactory domestic or agricultural water from this source is small.

About 0.5 mgd of shallow perched water is used for irrigation of the Waiehu Municipal Golf Course.

Potentials for Development

Surface Water

Most of the usable flows have already been developed. Some water is available for greater use in Makamakaole Stream and in Kahakuloa Stream.

Ground Water

Basal Water.--The basal ground-water body that underlies the area between Waikapu and Waihee Valleys is the most promising source of additional ground water. The net recharge to that part of the basal-water body lying between Iao Valley and Maalaea has been estimated at about 28 mgd by Caskey in 1968. Most of this recharge occurs in between Iao and Waikapu Valleys. Using comparable figures and making allowances for changes in rainfall and irrigation acreage, the net recharge to the basal-water body between Iao and Waihee Valleys has been estimated at 27 mgd. This total of 55 mgd represents the estimated basal-water discharge from the principal basal-water aquifer.

Discharge from Waihee Valley to the north boundary has been estimated at 5 to 10 mgd.

Dike-Impounded Water.--Drilled wells in areas underlain by dike-impounded water may be feasible development for additional supply of domestic-quality ground water. Advantage would be the addition of usable natural storage, but long-term withdrawal from this source will result in comparable reduction in the base flow of the dike-impounded water. Theoretically, the potential developable supply is the visible base flow of 47 mgd.

Perched Water.--Perched water, except in a few instances, is probably an uneconomical source for development.

Area III

This area is about 250 square miles in area and comprises the western slopes of Haleakala and the isthmus, which lies between East and West Maui.

Geology

The area lies between and includes the northern and part of the southwestern rift zones of Haleakala. The rocks include lava flows and pyroclastic deposits of three major sequences of Haleakala--the Honomanu, the Kula, and the Hana Volcanic Series. The rocks on the surface are mostly massive lava flows of the Kula Volcanic Series except in the southwestern part where the Kula is overlain by highly permeable Hana lava flows and in the isthmus area where the Kula is overlain by alluvium and calcareous dune sand. The Kula is at least 2,500 feet thick near the summit but only 50 to 200 feet thick near the shore. Honomanu rocks are completely overlain by the Kula rocks, except for a small outcrop in lower Maliko Gulch in the northern part. Calcareous dune sands compose most of the surface rocks along the northern and southwestern shores.

The highly permeable Honomanu rocks, although mostly overlain by the Kula, constitute the chief aquifer. The less permeable Kula is not an important aquifer but carry small quantities of perched water at high altitudes and basal water near the coast. The highly permeable Hana likewise carry small quantities of perched water at high altitudes and basal water near the coast. More importantly, however, the Hana provides a blanket of highly permeable rocks to absorb rainfall in the drier southern part.

The area, except for the northeastern part, is little eroded. The distribution of the principal rock units is shown in a generalized geologic map (fig. 42).

Rainfall

Rainfall on Haleakala is highest on the northeastern slopes (Area IV) between altitudes of 2,000 to 4,000 feet. Area III, most of which comprises the western slopes, lies to the west of the high rainfall area and receives little of the orographic rainfall. Mean rainfall ranges from about 15 inches in the southwestern part to about 200 inches in the eastern part. Average rainfall in the area is about 36 inches per year, which is equivalent to 450 mgd. About a third of this amount falls near the eastern boundary on about 10 percent of the area. The rainfall map (fig. 43) was taken from the National Weather Service map prepared in 1955.

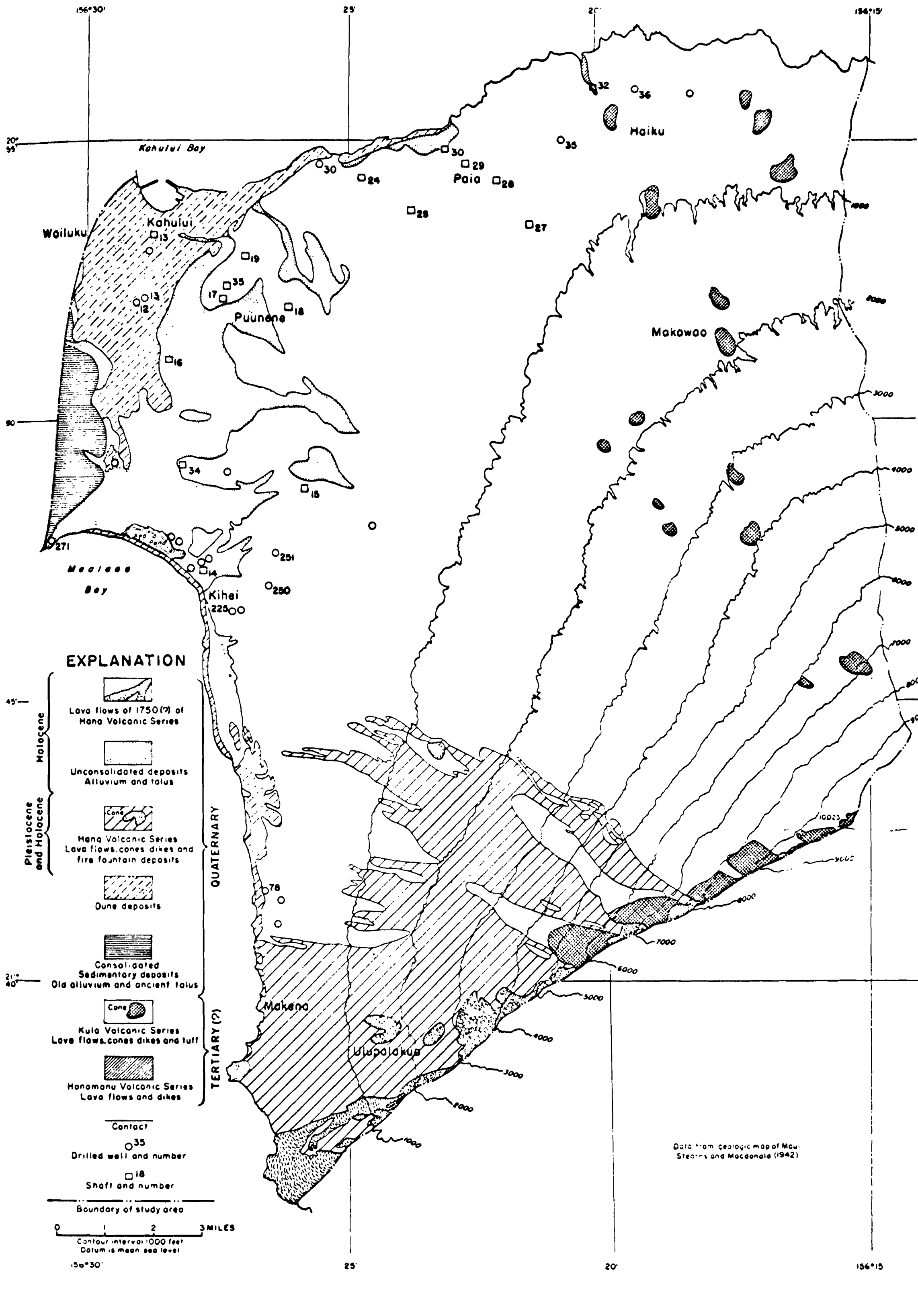


FIGURE 42. GENERALIZED GEOLOGIC MAP, AREA III.

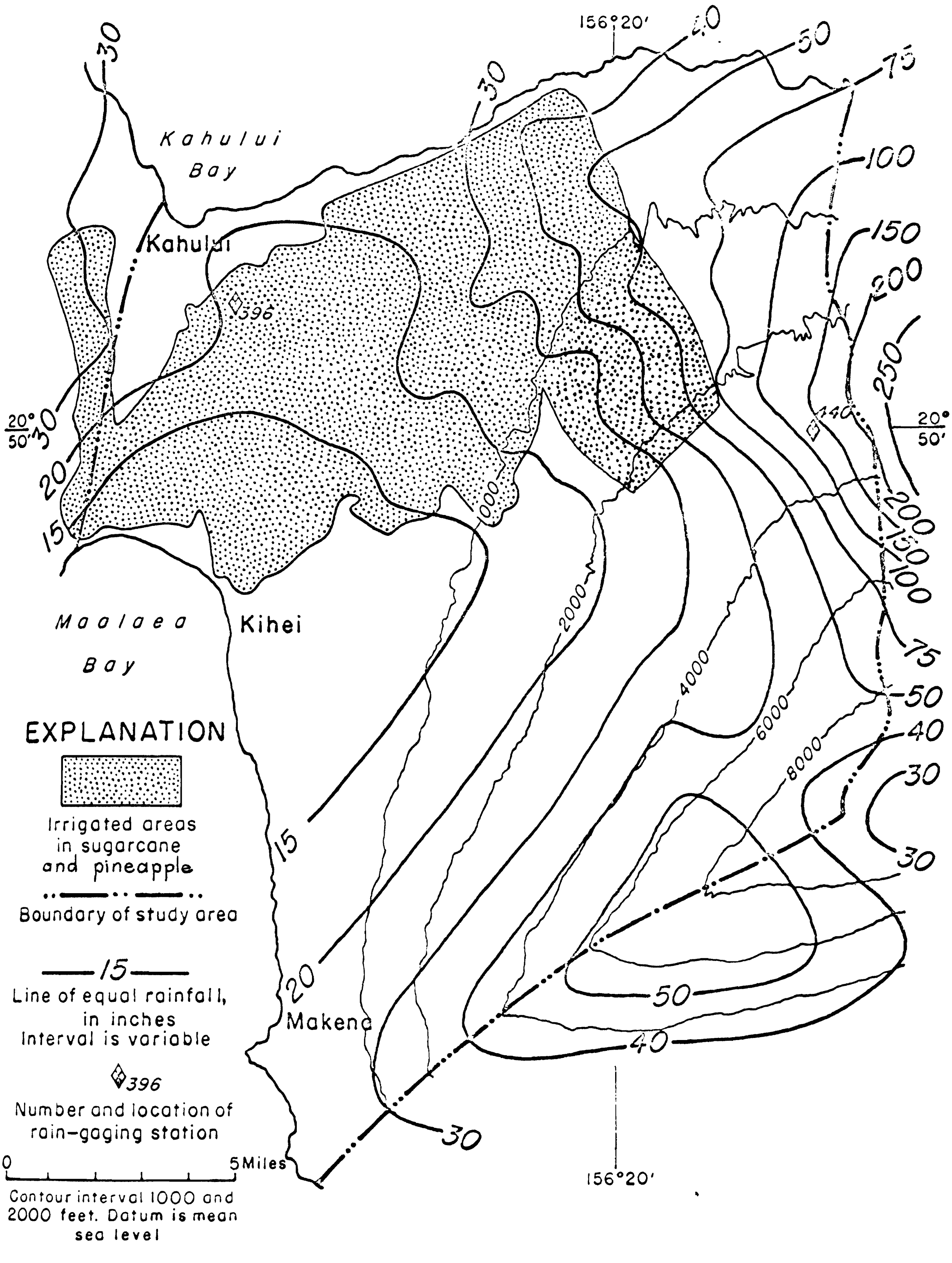


FIGURE 43. AREAL DISTRIBUTION OF RAINFALL, AREA III.

Surface Water

Perennial streamflows in this area occur only in the upper reaches of streams east of Maliko Gulch. Low and medium flows of these streams contribute about 10 mgd to the irrigation system that originates in northeastern Haleakala. About 2 mgd is also diverted from these streams for domestic use in nearby communities, but during dry periods, water from the irrigation system is needed to supplement this source.

Elsewhere in the area, streams flow only in times of extremely heavy rains.

Ground Water

Ground water occurs as perched water and basal water and probably as dike-impounded water in rift zones. Ground-water conditions especially for basal water have been greatly altered by the large import of irrigation water into the area. Perched water and dike-impounded ground-water bodies were little affected because they mostly lie outside the irrigated areas.

There are no known large perched-water bodies in the area, but small ones provide important sources of water at high altitudes. A total flow of slightly more than 100,000 gallons per day (gpd) has been measured from tunnels and springs tapping perched-water bodies. Of this 100,000 gpd flow, about half occurs along or near the southwestern rift in perched-water bodies in the Hana rocks. The other half occurs in scattered tunnels dug into Kula rocks in the rainier eastern part. Most sources flow less than 10,000 gpd.

There is no known occurrence of dike-impounded water. Water is probably impounded by dikes at lower levels deep in the rift zones, but this is not indicated at the surface because valleys are not deep enough to tap it.

Most ground water is stored in basal-water bodies. Recharge is principally from rainfall and irrigation water. About 160 mgd of water is imported from the northeastern Haleakala area for sugarcane irrigation in the lower western slopes of Haleakala. An additional 11 mgd of irrigation water is taken from streams in the rainier eastern part of this area. Without this recharge, which started in 1878, basal water underlying most of the lower western and southwestern slopes of Haleakala would be moderate to high in salinity and pumpage of 170 mgd of basal water for irrigation would have been impossible because of excessive rises in salinity. In addition to water for irrigation, about 5 mgd is imported for municipal use. Of this amount, about 3 mgd is piped in at altitudes of about 4,000 and 3,000 feet from the northeastern Haleakala area, and about 2 mgd is pumped from wells located in West Maui. The County also takes about 2 mgd for municipal use from the irrigation ditches. Near instantaneous static water-level contours of basal water underlying the irrigated area are shown in figure 44. Also shown are the chloride contents of the water from basal-water sources in the western Haleakala area.

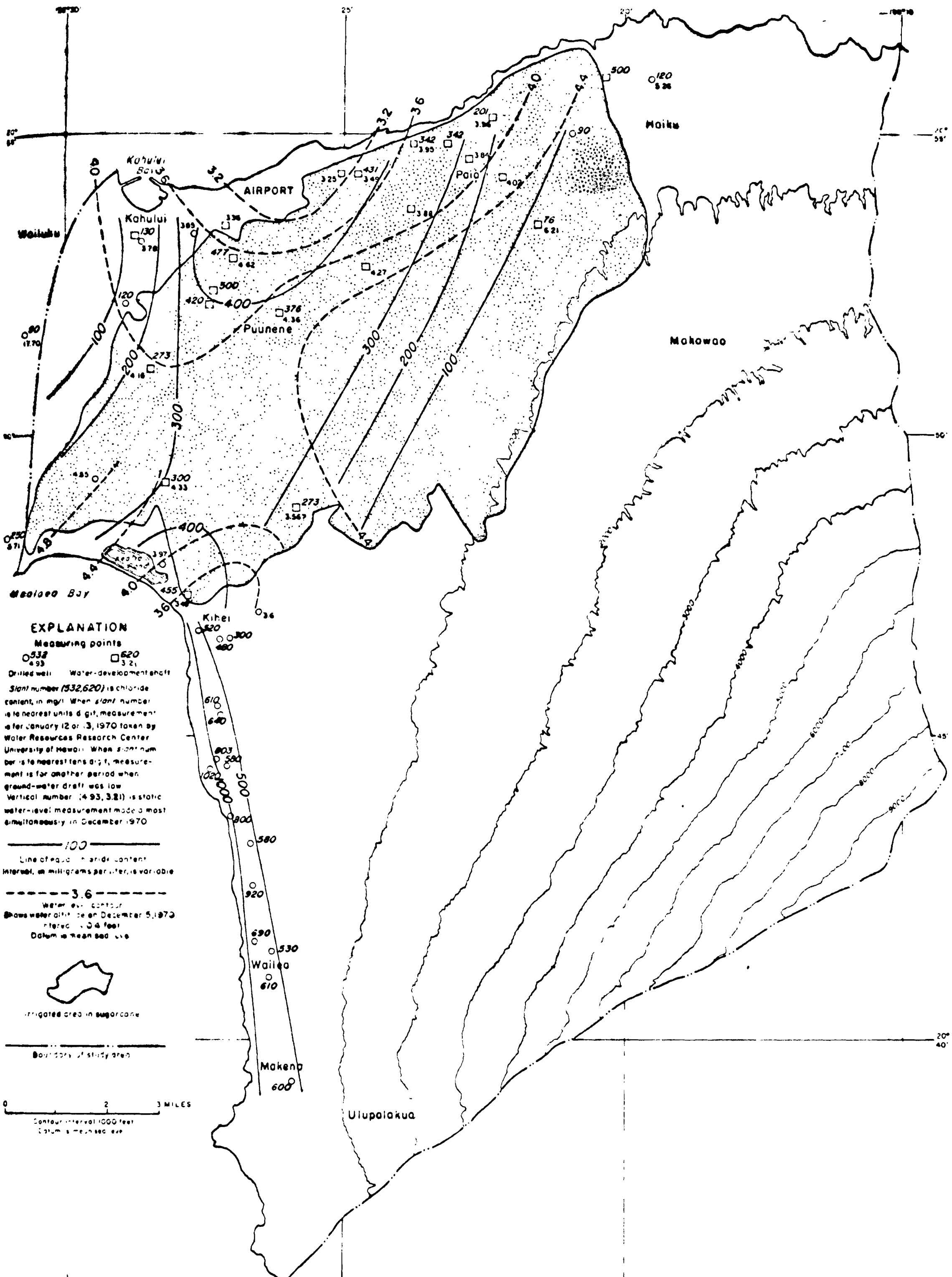


FIGURE 44. LINES OF EQUAL CHLORIDE CONTENT AND WATER-LEVEL CONTOURS, AREA III.

Ground Water between the Eastern Boundary and Maliko Gulch

This area is located within the northern rift zone of Haleakala and receives part of the high rainfall of the northeastern Haleakala area. There are many small perched-water bodies in the higher altitudes in cinder cones and in the surface Kula lava flows. Most are short-lived, but at least seven of the more persistent have been tapped by tunnels. The combined flow of the tunnels has been reported to be about 32,000 gallons per day. Dike-impounded water likely exists at depth but there is no expression of it at the surface because valleys are not cut deep enough to tap it. Exploration for dike-impounded water by drilling has, so far, been insufficient to identify and confirm its occurrence. Ground water probably occurs as basal water near the coast where dikes at or near sea level are likely to be sparse.

In 1973, there was almost no ground water being developed in this area, which appears favorable for development of water suitable in quality for domestic and municipal supplies. Development by wells rather than tunnels or shafts seems best because of the following:

1. There is no evidence of shallow dike-impounded water.
2. Shallow perched-water bodies are likely to be small and of small yield.
3. The most permeable rocks are lava flows of the Honomanu Volcanic Series, and they are found only at depths near sea level beneath the lower slopes.

The wedge-shaped area includes about 42 square miles where the average rainfall is about 85 inches per year, which is equivalent to 170 mgd. This compares with an average rainfall of 36 inches per year for the area. Total water development is a reported 0.03 mgd of tunnel flow and 11 mgd of streamflow for irrigation on the drier western slopes.

Streamflow information is limited to very short-term records of a few perennial streams at high altitudes. Without adequate streamflow information, ground-water flow cannot be estimated without first estimating the streamflow in the area. Streamflow information is available in the area to the east from Honopou to Keanae Valley, where the geology is similar. If this information can be transferred after making allowances for rainfall and evaporation differences, a very rough estimate of ground-water recharge can be made as follows:

	Keanae to Honopou	Honopou to Maliko Gulch		
	Inches per year	Inches per year	Mgd	Mgd per average
Rainfall	250	85	170	170
Streamflow	160	35-45	70-90	80
Evapotranspiration	20	30-40	60-80	70
Ground-water recharge	70	0-20	0-40	20
Ground-water flow per shoreline mile				4

The ground-water flow per mile figure of 4 mgd should be as a rough guide in considering the location of wells in relation to spacing and to distance from the shore.

Ground Water between Maliko Gulch and Kihei

This area includes all the sugarcane fields of the Hawaiian Commercial and Sugar Co., which occupy 34,000 acres below an altitude of 1,100 feet (fig. 44). The isthmus in the lower part includes an additional 500 acres of sugarcane fields of the Wailuku Sugar Co. Pineapple fields are scattered upslope of the sugarcane to about an altitude of 2,600 feet. Many truck farms are found above this level to about an altitude of 3,000 feet. Pasture lands begin at about an altitude of 500 feet and occupy large areas in the middle slopes of Haleakala.

An average of 190 mgd of water is imported in ditches into the area for sugarcane irrigation. Of this about 160 mgd is imported from the northeastern Haleakala area, about 10 mgd from the area between Honopou and Maliko Gulch, and about 20 mgd from West Maui.

The largest and main source of ground water is basal water. Most of the water is pumped from 17 water-development shafts. An average of 166 mgd was pumped from them for sugarcane irrigation and 1 mgd for use in a pineapple cannery. In addition, about 110 wells have been drilled, mostly for lawn irrigation. Water pumped from drilled wells is also used for a swimming pool, passion fruit and seed-corn irrigation, prawn cultivation, and cooling. Total pumpage from drilled wells averages less than 5 mgd.

All the shafts and wells are either within the irrigated area shown in figure 44 or downslope from it. This area covers 66 square miles, of which about 55 square miles is in sugarcane fields. The average ground-water pumpage of about 170 mgd represents about 40 percent of the total average input of 430 mgd of water, which falls as rain or is applied for irrigation. The total average input to the irrigated area is made up of 70 mgd of rainfall, 190 mgd of ditch water, and 170 mgd of ground water pumped.

Evapotranspiration losses are estimated at 240 mgd, of which 230 mgd are losses from the sugarcane fields and 10 mgd from areas within the irrigated area not planted in sugarcane. Unknown quantities include streamflow into the area from upslope and out of the area into the ocean, ground water as underflow into the area, into the area from West Maui, and out of the area into the ocean.

The area above the irrigated fields is about 33 square miles and receives an average rainfall of 35 inches per year or equivalent to about 55 mgd. Only part of this rainfall input enters the ground as recharge. About half of this input of 55 mgd runs off during storms into the irrigated fields and out to sea without any significant contribution to ground-water recharge. Another part is lost to evapotranspiration.

In considering the whole area from Maliko Gulch to Kihei, the following rough estimate of ground-water recharge is made.

	Maliko Gulch to Kihei		
	Irrigated areas mgd	Above irrigated area mgd	Total mgd
Rainfall	70	55	125
Ditch inflow	190	-	190
Ground water for irrigation	170	-	170
Evapotranspiration	240	20	260
Streamflow	35	25	60
Ground-water recharge			165

The ground-water recharge figure of 165 mgd compares with the figure of 170 mgd for ground-water pumpage. This figure is also somewhat substantiated by the quality of the ground water underlying the irrigated area, which shows the effects of irrigation water return and recycle. Although water from heavily pumped individual pumping stations show as much as tenfold increases in chloride content, the increase is not permanent, indicating some average annual parity between ground-water recharge and ground-water pumpage. It is likely that reduced ditch flows during the summer months cause overdraft during this period.

In the area west of the town of Kahului, the good quality of basal water underlying the isthmus suggests that a large quantity of good-quality underflow is moving in from West Maui.

Ground Water in the Kihei-Makena area

About 50 wells have been drilled since 1945 in this area. All tap basal water, mostly in volcanic aquifers. Surface rocks include lava flows and cinders of the Kula and Hana Volcanic Series, as well as shallow deposits of dune sands and alluvium. Of the 50 wells, about half are unused. None of the wells tap water of suitable quality for domestic use. About 2 mgd of water is pumped, mostly for the golf links at Wailea and truck farms near Kihei. Lawn irrigation at residences accounts for the rest.

The area covers about 130 square miles and receives an average rainfall of 24 inches per year, equivalent to 150 mgd. Most of this input of rainfall runs off during storms or is lost to evapotranspiration. Ground-water pumpage equivalent to the flow of ground water of about 1 mgd per shoreline mile has not significantly affected the chloride content of ground water in the Wailea area.

The chloride content of the water from wells ranges from about 500 to about 1,500 mg/l. The quality is better near Kihei because it lies adjacent to irrigated fields to the north and west and receives recharge from irrigation-water return. The higher slopes, which include the upper Ulupalakua area, are situated at altitudes too high for economical development of basal-water supplies. Except for some small springs, there is little to indicate the presence of any large perched-water bodies in these areas.

Although in the rift zone, basal-water conditions likely prevail in coastal areas underlying the lower slopes of the Ulupalakua area. This is likely because dike-free lava flows of the Hana Volcanic Series extend to some depths below sea level.

Present Use of Water

Surface Water

Present use of water is described on page

Ground Water

About 170 mgd of ground water is pumped, of which about 165 mgd is used for sugarcane irrigation. The remaining 5 mgd is used for passion-fruit irrigation, seed-corn irrigation, lawn and truck-farm irrigation, and in a pineapple cannery. Not included in the total is an undetermined quantity of brackish and saline water pumped for prawn cultivation and cooling. No water is pumped for domestic use.

Some perched water at high altitude is diverted for irrigation and domestic use. The quantity is estimated to be less than 10,000 gpd.

Potentials for Development

Surface Water

Most of the available surface water from this area is already being diverted and further development may be infeasible under present conditions.

Ground Water

The area between Honopou and Maliko Gulch appears the most favorable for development of water suitable in quality for domestic and municipal use. Some domestic-quality ground water, little or unaffected by irrigation-water return, is available above an altitude of 1,100 feet or above the irrigated area. However, at this altitude, the supply is limited and depends on the rainfall available and the ability of the surface rocks to absorb the rainfall. Good quality basal water originating in West Maui underlies the area west of Kahului but this supply can best be developed in West Maui for domestic supply.

A good supply of water in the chloride range of 500-1,500 mg/l exists in all coastal areas in the western part.

The supply of perched water is limited and that of dike-impounded water has yet to be explored. The latter will require the drilling of wells more than 1,500 feet deep.

A rough accounting of the disposition of 685 mgd rainfall in the area which is augmented by a water import of 180 mgd for a total water input of 865 mgd is:

		Mgd
Runoff	=	325
Irrigation and evapotranspiration	=	395
Surplus to ground water	=	145

Much of the surplus to ground water takes place during infrequent storms. Owing to small storage in thin basal-water lens, which prevails in much of the area, a large part of the surplus to ground water is lost to the sea.

Area IV

This area, about 134 square miles, comprises the northeastern and eastern slopes of Haleakala between Kailua and Hana.

Geology

This area is between and includes part of the northern and eastern rift zones of Haleakala. The oldest rocks are basalts of the Honomanu Volcanic Series, which form the bulk of the dome. The uppermost part of the Honomanu is transitional to the overlying Kula Volcanic Series, which covered the dome. Kula rocks include andesites and andesitic and picritic basalts. The eruption of the Kula Volcanic Series was followed by a long period of quiescence, during which time deep canyons were carved into the dome. The last sequence of rocks is called the Hana Volcanic Series. These rocks filled deeply eroded and alluviated canyons and veneered most of the slopes of northeastern Haleakala.

Rainfall

Rainfall on Maui is heaviest in this area, especially between altitudes of 2,000 and 4,000 feet. Based on the map shown as figure 45, the average rainfall for the area is estimated to be about 144 inches per year, or 925 million gallons per day.

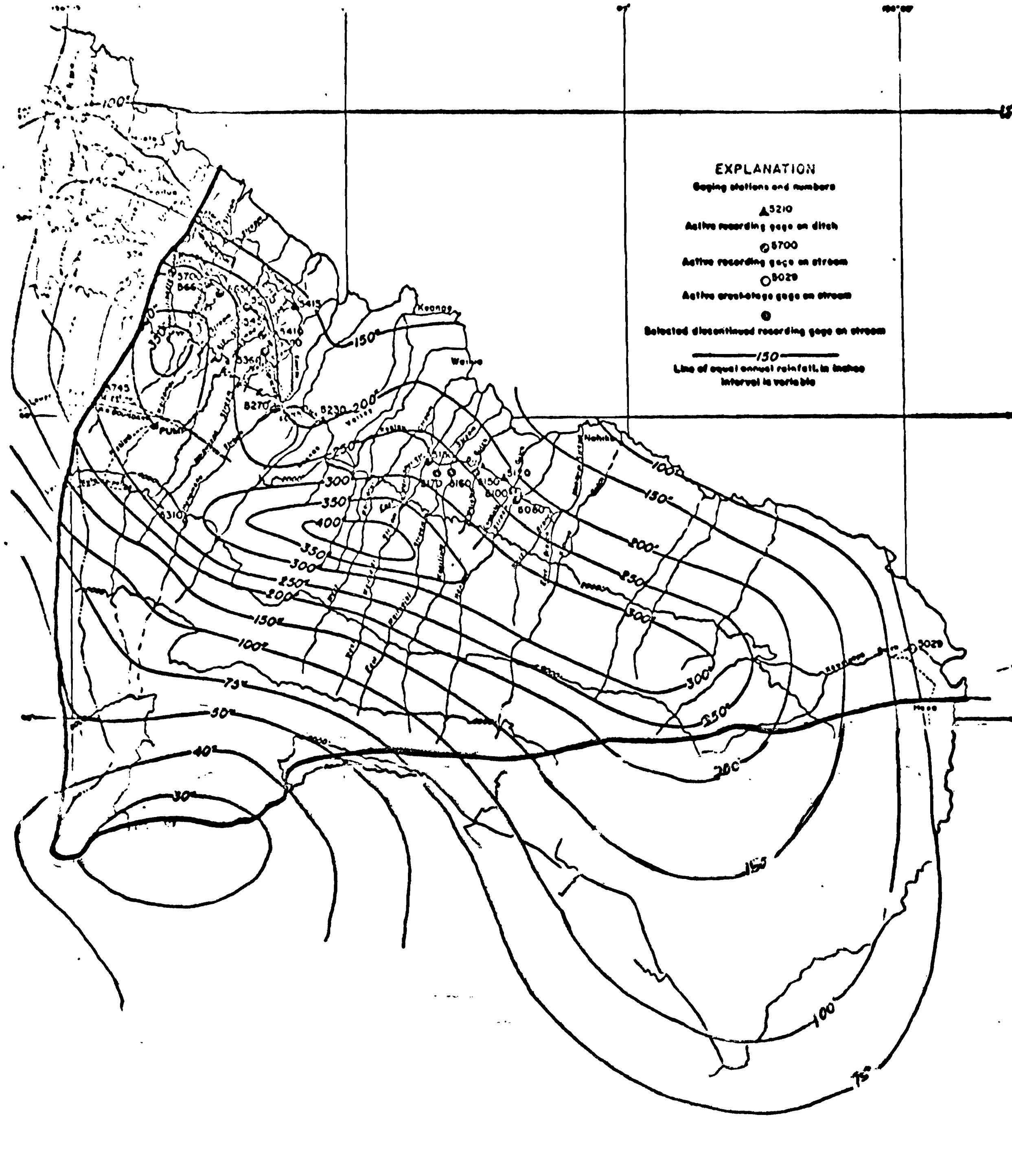


FIGURE 45. AREAL DISTRIBUTION OF RAINFALL, AREA IV.

Surface Water

Areal Distribution

Precipitation is abundant in this area, with annual rainfall averaging as much as 400 inches in places (see fig. 45). Where surface rocks are not permeable, surface runoff is large. On the other hand, where the surface consists of extremely permeable fresh flows of the Hana Volcanic Series, most of the rain soaks into the ground, not reappearing on the surface. Streamflow is very infrequent, under these conditions, and reaches the ocean only in times of flood.

Streams west of Makapipi are perennial. Records show that discharge of these streams at the 1,200-foot level of the highest ditch of the East Maui Irrigation Co. system, averages in excess of 200 mgd. This system takes an average of about 160 mgd from this abundant source to the drier areas of western Haleakala for the irrigation of sugarcane.

West of Honomanu, the system consists of four ditches at different levels and captures nearly all the low and medium flows of the streams, leaving only excess high flows to flow to the sea. Only one of these ditches, the Koolau, at the 1,200-foot level, extends east of Honomanu, and streamflow in excess of the carrying capacity of this ditch, along with about 35 mgd of ground water, which arises below the ditch level, flows mostly unused into the sea.

Streams east of Makapipi are ephemeral in spite of abundant rainfall because the surface rocks are extremely permeable. All but the heaviest rains sink rapidly into the ground. Floods have occurred, at times resulting from overflow in the lower reaches of the normally dry streams.

The percentage of rainfall that runs off as surface water is extremely high in certain parts of the area, but in other areas where surface rocks are fresh, as in Keanae in the Hana area, most of the rain enters the ground.

In addition to the irrigation system, a domestic water system belonging to the Maui County Department of Water Supply takes water from streams between Waikamoi and Honomanu. The upper Kula pipeline taps these streams at an altitude of about 4,000 feet and delivers water to western Haleakala. A lower Kula pipeline completed recently diverts from the streams at an altitude of about 3,000 feet.

An interconnection between the pipelines exists at Waikamoi, and water from the more plentiful source at the 3,000-foot altitude can be pumped up to the upper line.

Seasonal Variation

Duration curves of several streams at gaged points in the area are shown in figure 46. These represent natural conditions as the gaging stations are located upstream of all points of diversion.

Low-flow frequency data for several streams are shown in figure 47. Data from most of the streams indicate a lack of sustained base-flow discharge.

The immediate response of runoff to rainfall is evident in studying peak flows in the area, with peak discharges ranging up to 8,000± cfs per square mile. Even in the area where streambeds are normally dry, peak flows may range up to 2,250 cfs per square mile (Moomoonui Gulch at Hana, drainage area 0.90 sq mi, 1968).

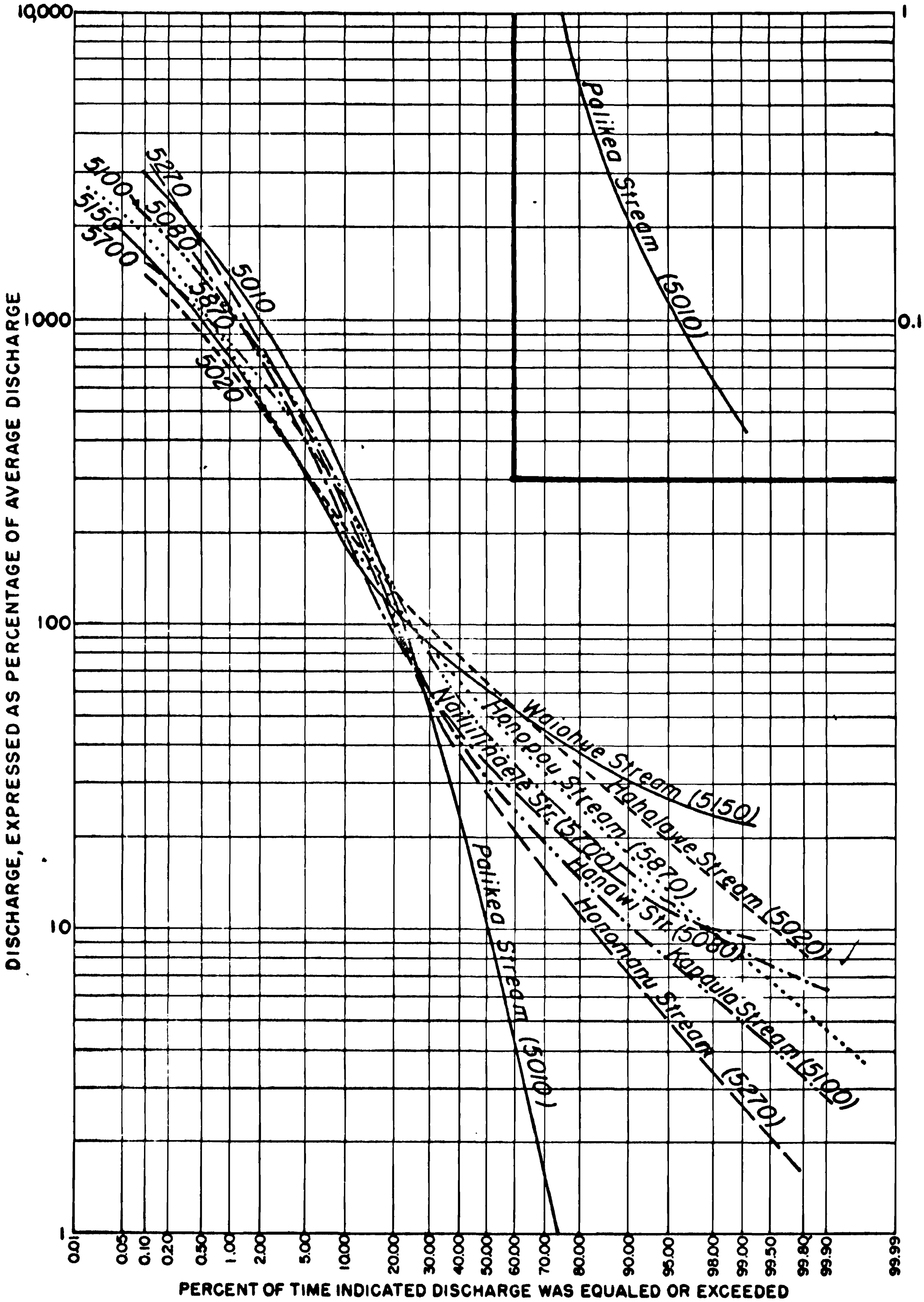


FIGURE 46. FLOW-DURATION CURVES OF DAILY FLOWS FOR SELECTED STREAMS.

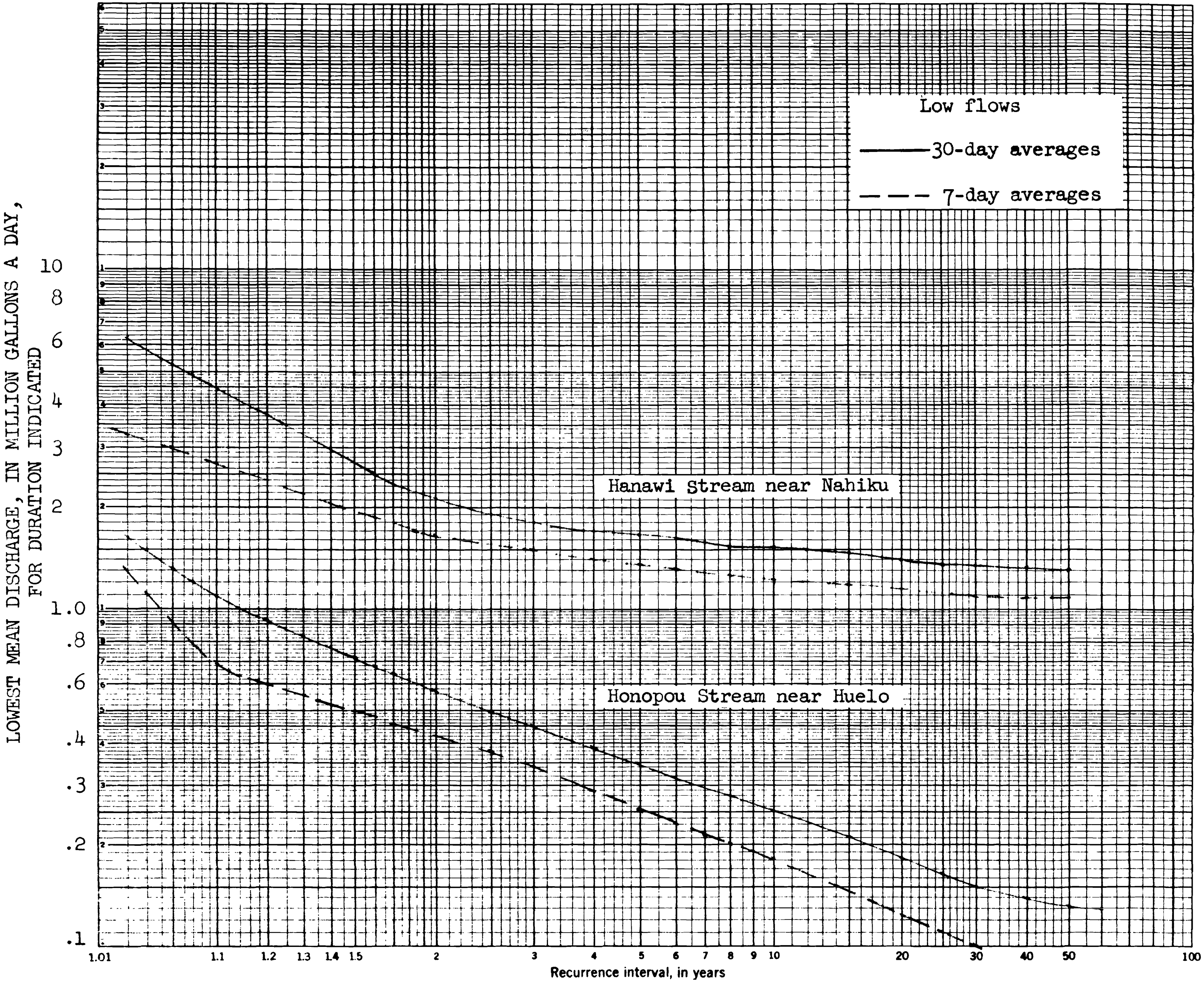


FIGURE 47. LOW-FREQUENCY CURVES FOR SELECTED STREAMS, AREA IV.

Ground Water

The occurrence of ground water has been extensively explored by numerous test holes in the Nahiku area. Elsewhere, there is little or no ground-water information and only general descriptions of its occurrence are available.

The availability of ground water is largely controlled by the ability of the surface rocks to absorb the abundant rainfall. Where the rocks are poorly to only fairly permeable, as are the Kula rocks in about half the area, much of the rain is dispersed as overland runoff in streams, which are mostly perennial, and only a small part of the rain infiltrates as ground-water recharge. Where the surface rocks are highly permeable, as are the Hana rocks, much of the rain enters the ground as recharge to ground-water bodies, and overland runoff is low and streams are mostly intermittent. Some of the intermittent streams become perennial at low altitudes near the coast, where they are fed by discharging ground water.

In most places, infiltration is not deep but is limited to or is temporarily detained in small and shallow water bodies. These water bodies, mostly perched, provide the base flow of springs and streams where they intersect the land surface. If they do not discharge at the surface, they provide recharge to deeper water bodies by leakage and spillage from storage.

Owing to the abundance of rainfall and the heterogenous nature of the near-surface rocks, many shallow perched-water bodies occur at all altitudes in the Kula and Hana rocks. Other shallow water bodies include basal-water bodies in Kula and Hana rocks near coastal area where they extend below sea level.

Deep ground-water bodies include perched water in the upper transitional Honomanu rocks. The water is perched in pervious pahoehoe and clinkery aa flows interbedded with dense aa flows. Also likely are deep basal and dike-impounded water bodies in Honomanu rocks.

Three perched-water bodies in the Nahiku area are of particular interest, a nonartesian water body in the Hana rocks, and two artesian water bodies in Honomanu rocks with artesian heads of 800 and 1,100 feet. The artesian aquifer is 50 to 200 feet thick and consists of a series of pervious pahoehoe and clinkery aa flows interbedded with dense aa flows in the upper transitional Honomanu rocks. The artesian bodies occupy the same aquifer and is probably separated by a dike or fault boundary. The artesian areas are shown in figure 48.

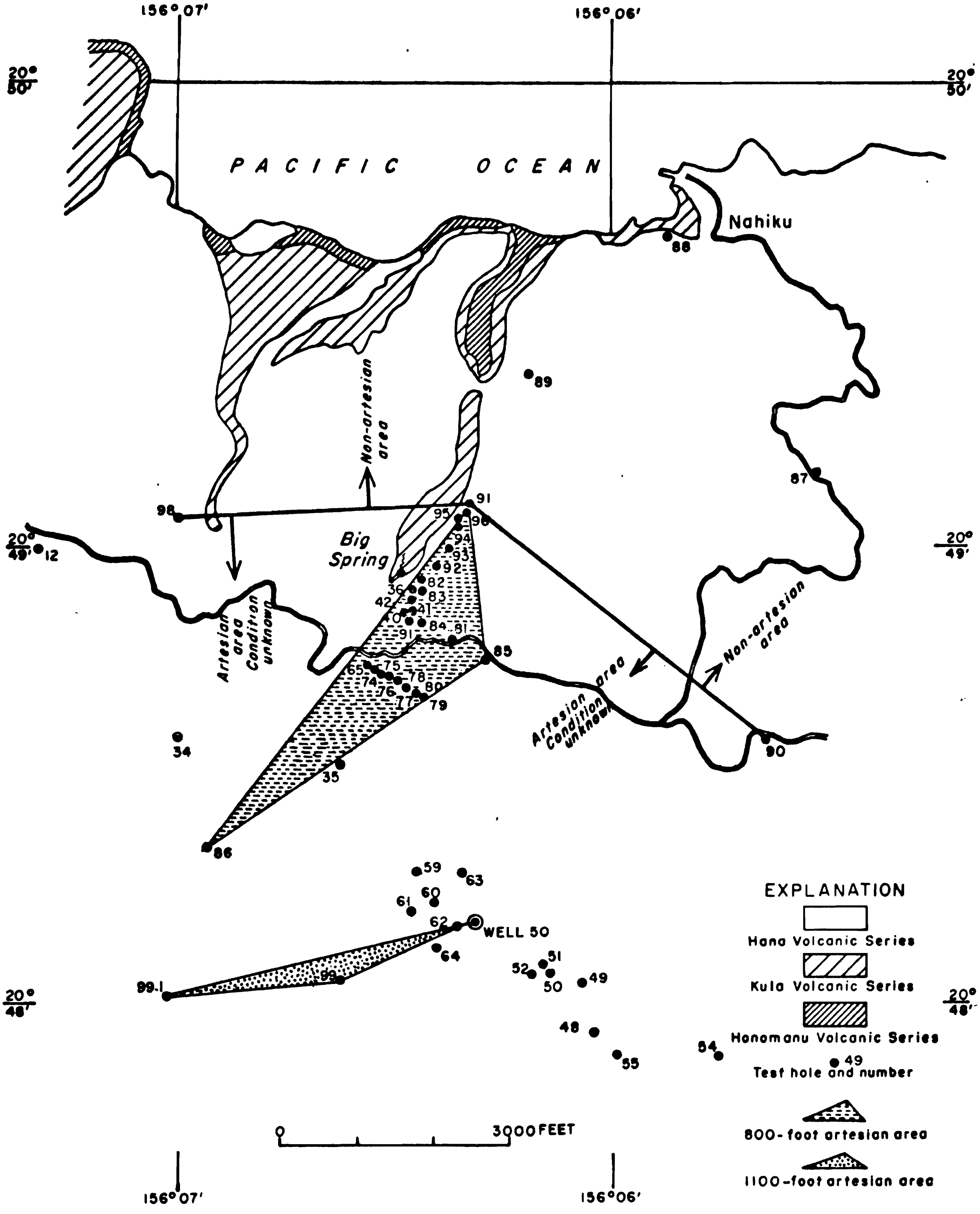


FIGURE 48. GEOLOGIC MAP OF NAHIKU AREA.

Diagrammatic sketches showing various perching and confining members and associated water bodies at different altitudes are shown in figure 49.

The availability of ground water can be discussed better by comparing areas underlain by Kula rocks with those areas underlain by Hana rocks instead of by geographical areas. Ground water has not been developed or even explored to any degree in Kula rock areas because streamflow is generally abundant and readily available at all altitudes up to 2,000 feet. Even though much of the rainfall is quickly dispersed as streamflow, recharge to ground water is still significant owing to the generally abundant rainfall. In the areas underlain by Hana rocks, the occurrence of ground water differs markedly between areas where Hana rocks extend below sea level and those areas where these rocks do not, as in the Nahiku area. Ground water is perched where Hana rocks are shallow and is basal where Hana rocks extend below sea level.

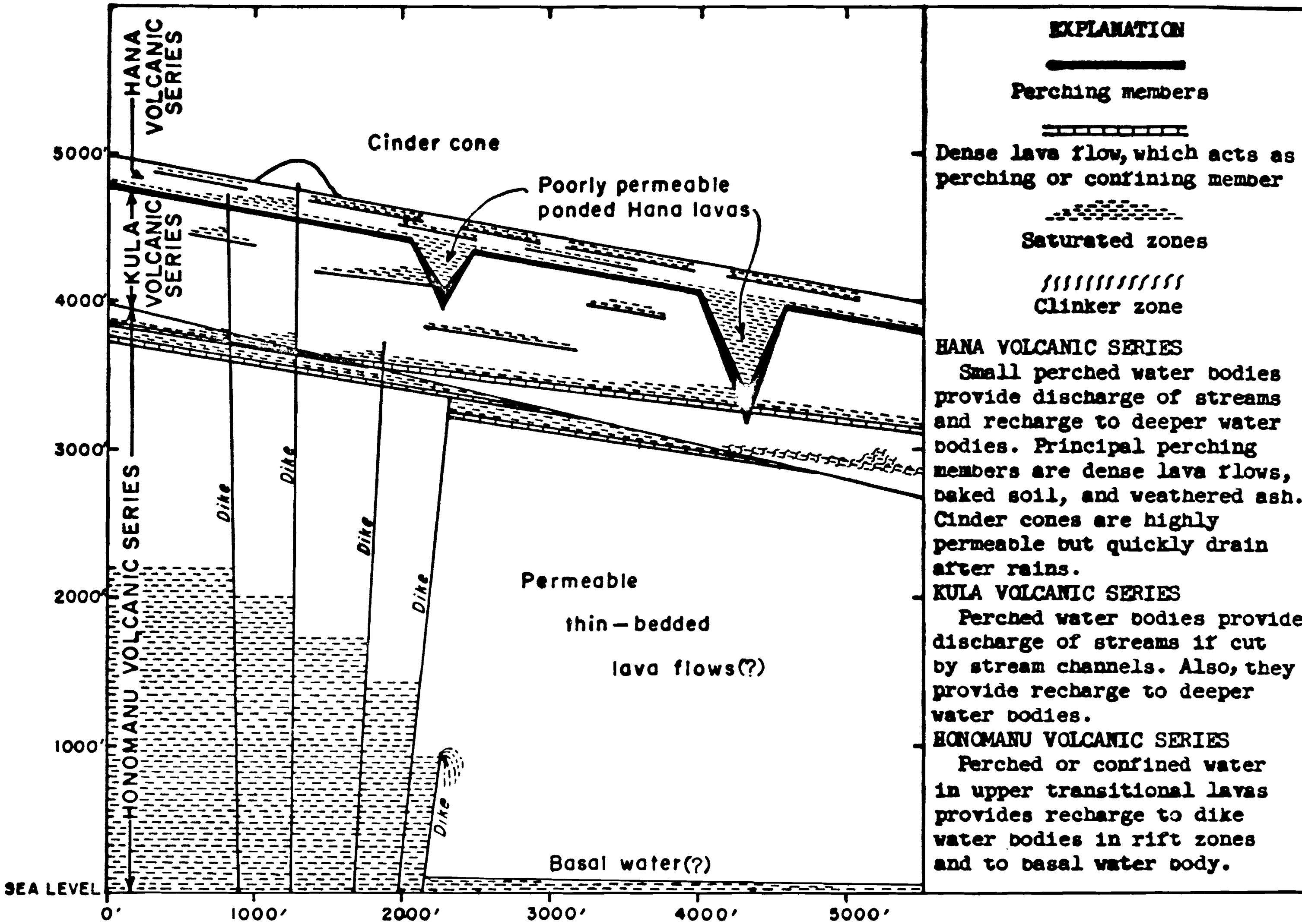


FIGURE 49. DIAGRAMMATIC SKETCHES SHOWING VARIOUS PERCHING AND CONFINING MEMBERS AND ASSOCIATED WATER BODIES AT DIFFERENT ALTITUDES.

The following table may be used as a guide in estimating the ground-water flow in the area. The following assumptions were made in preparing the table.

(1) Evapotranspiration is small and ranges from 10 to 20 percent of the average annual rainfall of 180 inches in the area.

(2) Streamflow ranges from 60 to 80 percent of the rainfall in areas underlain by Kula rocks and from zero to 25 percent in areas underlain by Hana rocks.

(3) The residual is ground-water recharge and potentially available for development. Owing to inflow from discharging ground water to the surface, which adds to the streamflow, this residual is calculated upgradient from the point where the streamflow estimate is made.

(4) The total rainfall input is 925 mgd and equally divided between areas underlain by Kula and Hana rocks.

(5) Ground-water flow is seaward.

(6) The shoreline distance normal to the ground-water flow is 13 miles for Kula rocks and 18 miles for Hana rocks.

	Mgd
Rainfall	925
Runoff	*310
Evapotranspiration	145
Ground-water recharge	470

*Indicates 160 mgd exported to Area III.

Where streamflow data are readily available, these should be used to calculate ground-water flow instead of the table. There is an apparent relation between rainfall and evapotranspiration, where the latter decreases as the former increases. The evapotranspiration can be smaller or greater than the range used. It is generally insignificant where the rainfall is very high but becomes increasingly more significant as rainfall decreases, especially in northeastern Haleakala, where much of the ground water is shallow.

Present Use of Water

Surface Water

Between Honopou and Makapipi, the low and medium flows of streams up to the capacity of the system are diverted and exported to the dry areas of western Haleakala, mainly for the irrigation of sugarcane. Several small communities along the way use this ditch water as the source for their domestic water. Diversion averages about 160 mgd, measured at Honopou.

Surface water is the main source for domestic water supplies in the villages located in this area and is also used for taro irrigation in certain areas.

Ground Water

Ground-water development in the area is small. Pumpage consists of about 100,000 gpd from the Hana Ranch well in Hana. Pumpage will be increased by 100,000 to 200,000 gpd in the Hana area when the State Division of Water and Land Development's new well is put into operation by the County for municipal supply. The discharge of tunnels tapping perched-water bodies have been estimated at about 6 mgd. Most of the flow is diverted to ditches, which carry the water to western Haleakala for sugarcane irrigation. The estimated discharge of perched-water springs is about 25 mgd. Most of the discharge is unused because much of the flow occurs below the level of the ditches.

Potentials for Development

Surface Water

Because of the heavy rainfall in this area, there is an abundant supply of water still available for development and exportation--the present usage is limited mainly by economic factors. If and when it becomes feasible, some of the water that flows in the streams below the level of Koolau ditch between Honomanu and Makapipi could be diverted to western Haleakala. This might be accomplished by extending the lower-level ditches that now stop west of Honomanu or by pumping the water up to the level of the Koolau ditch.

Ground Water

There is an abundant supply of ground water available for development, and like the stream supply, its development is mainly limited by economic factors.

The need for large supplies of water, both municipal and irrigation, will be in the dry areas of the western Haleakala area. Because of this great distance to the areas of need, the mode of transport of the developed ground water needs to be seriously considered. The choices are a new pipeline, the existing ditches, or extensions to the existing ditches.

Except for areas underlain by thick sections of the Hana rocks, which extend below sea level, the principal aquifer will be the Honomanu rocks. The Honomanu rocks contain perched-artesian water in its upper part in the Nahiku area with an artesian head of at least 1,100 feet in altitude. This artesian condition may or may not extend to other areas where water levels are likely to be closer to sea level. In the excepted areas, basal-water conditions probably prevail in the Hana rocks, the principal aquifer. Owing to the extreme perviousness of the fresh Hana rocks in places, some precaution must be taken in development to allow for the natural intrusion of seawater to the aquifer.

Smaller quantities of ground water are available perched in Kula and Hana rocks. These supplies, although generally small, provide important sources of water at high altitudes and in isolated places.

Area V

This area of about 167 square miles comprises the entire southern slopes of Haleakala.

Geology

Southern Haleakala lies between and includes part of the eastern and southwestern rift zones. In about half of the area, the surface rocks are lava flows of the Kula Volcanic Series. In the other half, the Kula rocks are overlain by highly permeable rocks of the Hana Volcanic Series. The oldest rocks are basalts of the Honomanu Volcanic Series, which form the bulk of the dome. These rocks are nearly totally covered by the younger Kula rocks. The Honomanu rocks are generally highly permeable except in the upper transitional part. Less permeable Kula rocks, which include andesite and andesitic basalts, is about 2,000 feet thick near the summit and only 50-200 feet thick near the shore. The eruption of the Kula rocks was followed by a long period of quiescence. After this period, Hana rocks erupted and filled deeply eroded and alluviated canyons and veneered the slopes near the rift zones. During the early part of this last eruptive period, the voluminous Kaupo mud flow, carrying blocks of consolidated cinders, moved down Kaupo Gap to the sea.

Rainfall

This area, lying on the leeward side of Haleakala, receives little of the orographic rainfall, except near its eastern boundary. Because of the great height and breadth of Haleakala, most of the rain falls on the windward slopes. Mean annual rainfall ranges from about 25 inches throughout the central part of the area, to about 250 inches near the eastern boundary, and to about 50 inches near its western boundary. Average rainfall is about 63 inches per year, which is equivalent to 500 mgd. Figure 50, showing lines of equal rainfall in the area, was drawn from a rainfall map prepared by the National Weather Service in 1955.

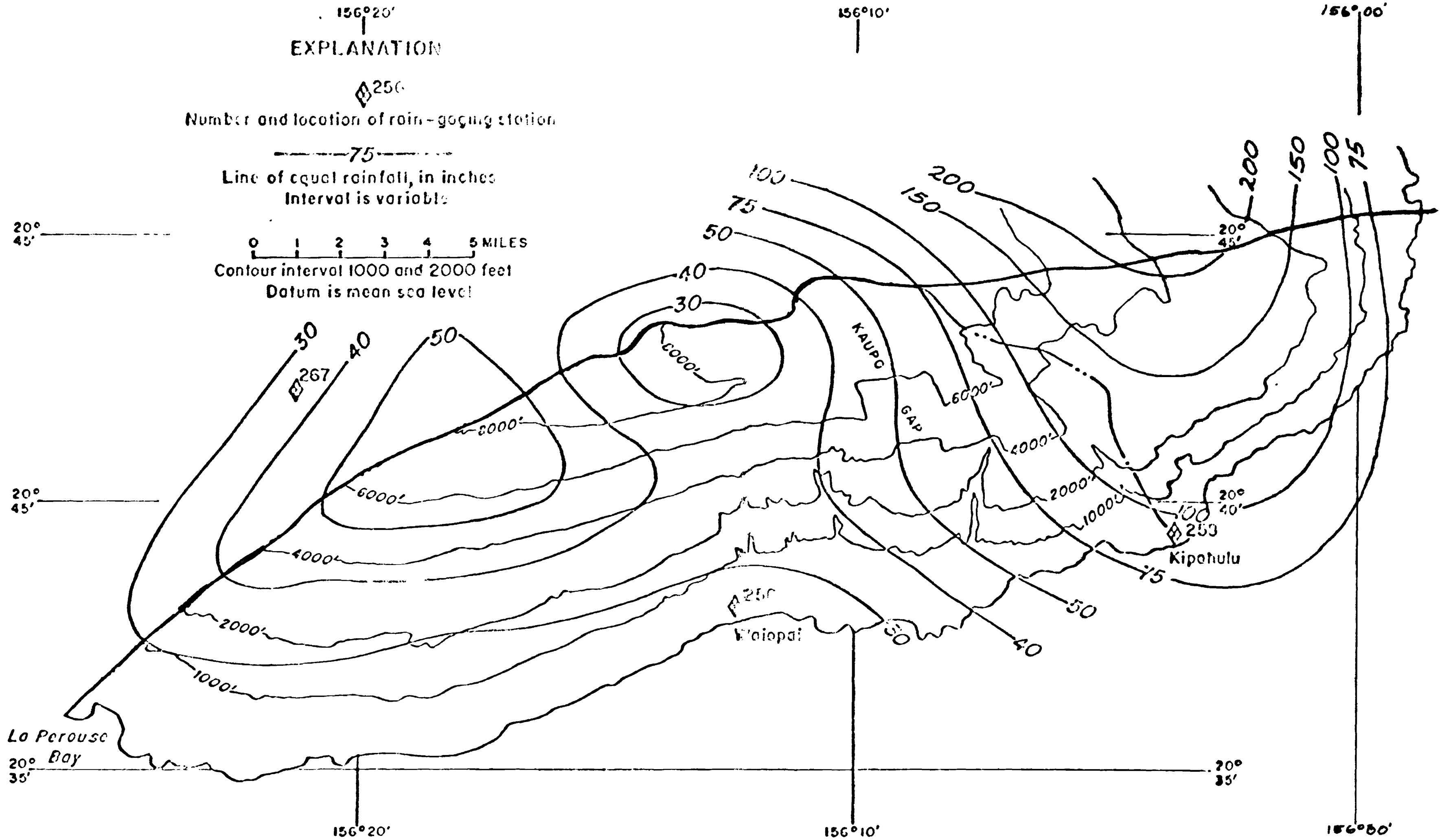


FIGURE 50. AREAL DISTRIBUTION OF RAINFALL, AREA V.

Surface Water

Streams in the area between Waihoi and Kipahulu are mostly perennial because the surface rocks are relatively impermeable. Water diverted from Wailua Stream is presently used for domestic purposes between Wailua and Hana.

Streams between Manawainui and Kipahulu are believed to be perennial in their upper reaches. However, at their mouths, they are either dry or only trickles after extended dry periods. Intakes are located in the headwaters of several streams to supply water for domestic and ranch use near Kaupo. Additional diversions, along with much larger storage facilities, would be necessary to increase the usage of streamflow in the area.

Streams west of Manawainui are usually dry because of light rainfall and highly permeable ground conditions. Measured streamflows in the area are summarized:

	Mgd
Palikea Stream	38
Hahalawe Gulch	3.5

Ground Water

Ground water occurs as perched water and as basal water, and very likely as dike-impounded water in rift zone.

Basal Water

Basal ground water occupies most of the rocks near sea level except deep in the rift zones where ground water is probably impounded by dikes. Basal water occurs in the lower part of rift zones, wherever dike-free permeable rocks extend below sea level.

The quality of basal ground water is good in coastal areas extending from the eastern boundary to Punahoa Spring near Kaupo. Basal water may not exist in lower Kaupo Gap if the Kaupo mudflow is extensive and the top of it lies mostly above sea level. If the top of the mudflow lies at shallow depths and below sea level, this would provide a desirable situation where seawater intrusion would be retarded by the mudflow.

The basal-water body underlying near-shore areas west of Kaupo Gap is probably brackish. The chloride contents of the water from two dug wells, one near Ulupalakua and the other, half-way between Ulupalakua and Kaupo, were 1,210 and 1,760 mg/l, respectively, in 1970.

Dike-Impounded Water

Water is probably impounded by dikes deep in the rift zones, but this is not indicated at the surface because valleys are not deep enough to tap it. The chances of obtaining fresh dike water by deep wells would probably be better in the rift zones than out of them.

Perched Water

Perched-water bodies, however small, because of their occurrence at all altitudes, provide very important sources of water in isolated places. They feed nearly all the springs in Haleakala National Park and Waiu Spring near the shore in Kaupo Gap. The largest perched-water body is in upper Manawainui Valley where interbedded tuff acts as the perching member in Honomanu lava flows. Discharge is about 350,000 gpd. Springs discharge near shore from a water body perched on the Kaupo mudflow. The flow of Waiu Spring was measured at 50,000 gpd in 1970. Total discharge of perched-water bodies in the area has been estimated at about 400,000 gpd, most of it from springs in Manawainui Valley. Most perched-water bodies are small and discharge from them is not always perennial owing to the generally low and inconsistent rainfall. Many springs go dry between rains.

Present Use of Water

Surface Water

The only diversions of surface water of any consequence are those from Wailua Stream for the area eastward to Hana, Kalepa Stream, and a tributary of Manawainui Gulch for domestic and stock use by Kaupo Ranch.

Ground Water

Present use and development of water is limited to small livestock and domestic supplies owing partly to the poor prospects of obtaining large quantities of low-cost water and partly to the lack of potential for any large-scale use of it. In 1970, the principal land use was grazing. The extent of the present use and development by the ranches and others in the area follows. Less than 2,000 gpd is pumped from two wells owned by Mr. Sam Pryor in Kipahulu for domestic and irrigation use at his residence.

Haleakala National Park.--The stage of water use and development in 1970 at Haleakala National Park is shown in figure 51.

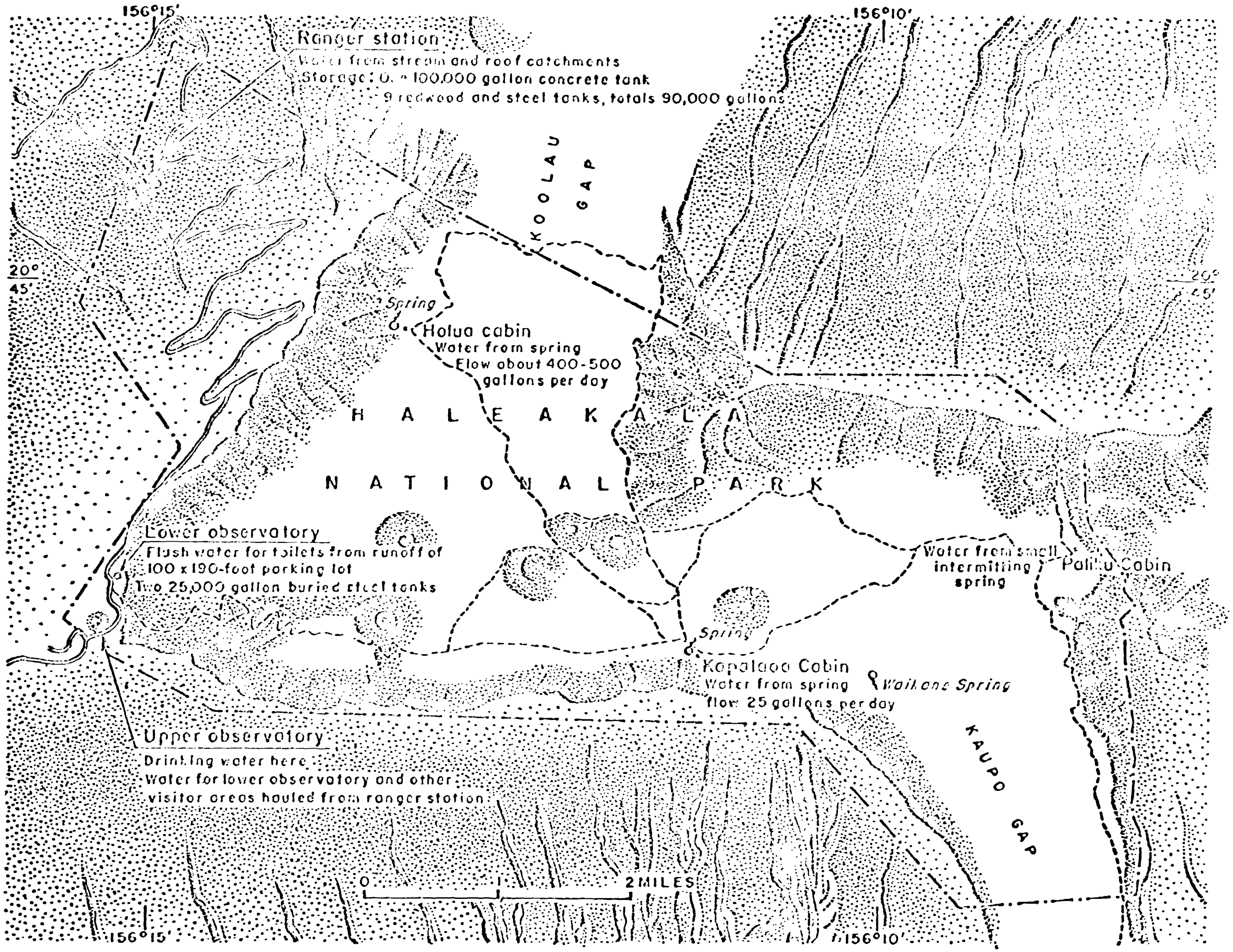


FIGURE 51. MAP SHOWING WATER DEVELOPMENT OF HALEAKALA NATIONAL PARK

Ulupalakua Ranch.--In 1970, all of the domestic water supply and much of the livestock supply were imported from the northeastern Haleakala area by the Kula pipeline. Other supplies and their local sources are shown in figure 52. The chloride content of the water from the near-shore dug well is more than 1,000 mg/l.

Maui Factors Ranch.--The main source of water is an 11-foot deep, 3-foot diameter near-shore dug well. The other source is the intermittent streamflow in Palaha Gulch, at about an altitude of 2,900 feet. The flow is diverted into a 1-million gallon open reservoir. The area shown in figure 53 is roughly the area covered by the Ranch.

Haleakala Ranch.--A pond located at an altitude of about 20 feet near the mouth of Waiopai Gulch is an important source of livestock water. Source of water is the intermittent streamflow in the gulch. The water is pumped to higher altitudes.

Another source of water is the 95-foot long tunnel in Pahihi Gulch at an altitude of 4,180 feet. Estimated yield is about 1,500 gpd.

Kaupo Ranch.--The principal water sources are shown in figure 54. The main County supply is the Kalepa Gulch intake.

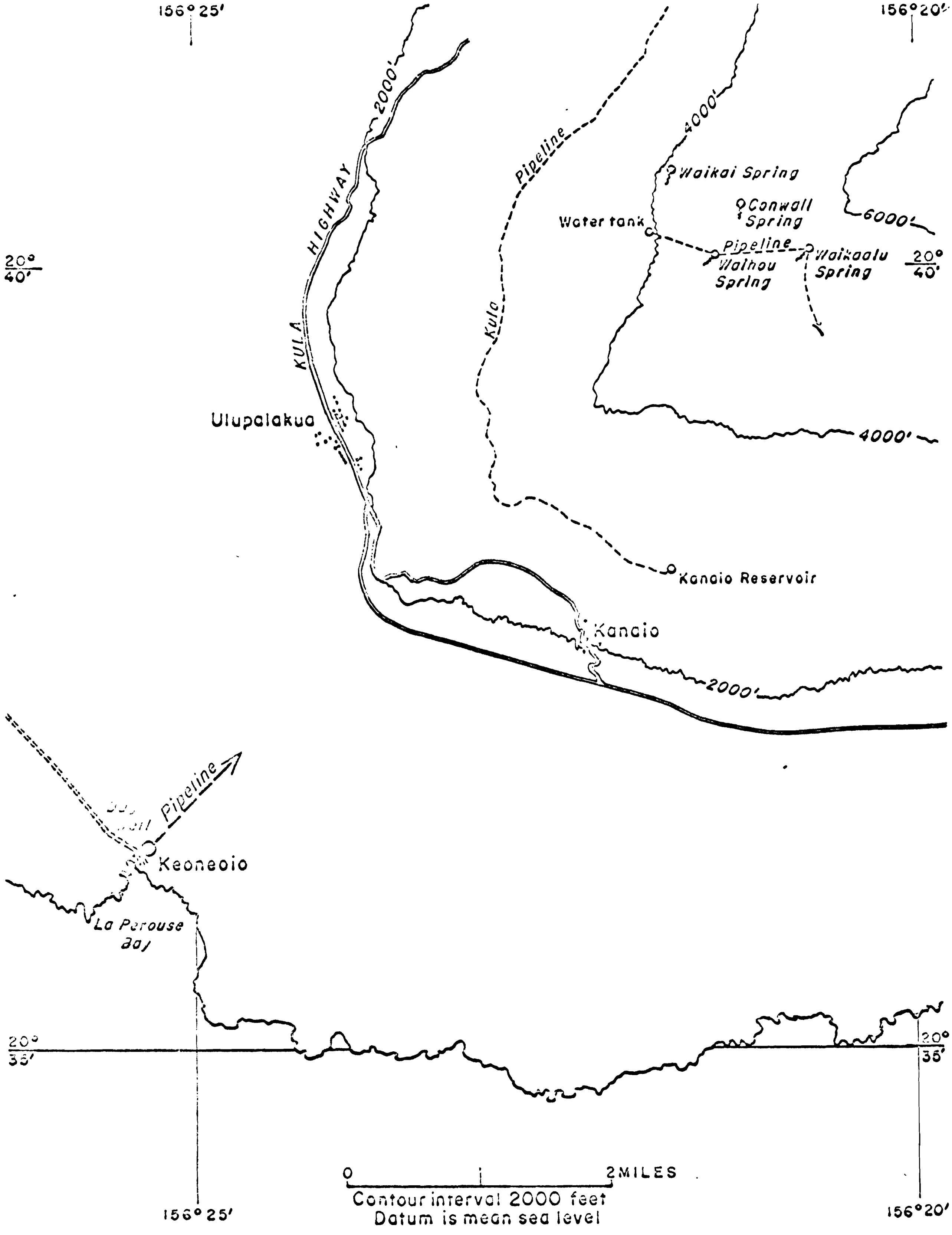


FIGURE 52. MAP SHOWING WATER DEVELOPMENT OF ULUPALAKUA RANCH

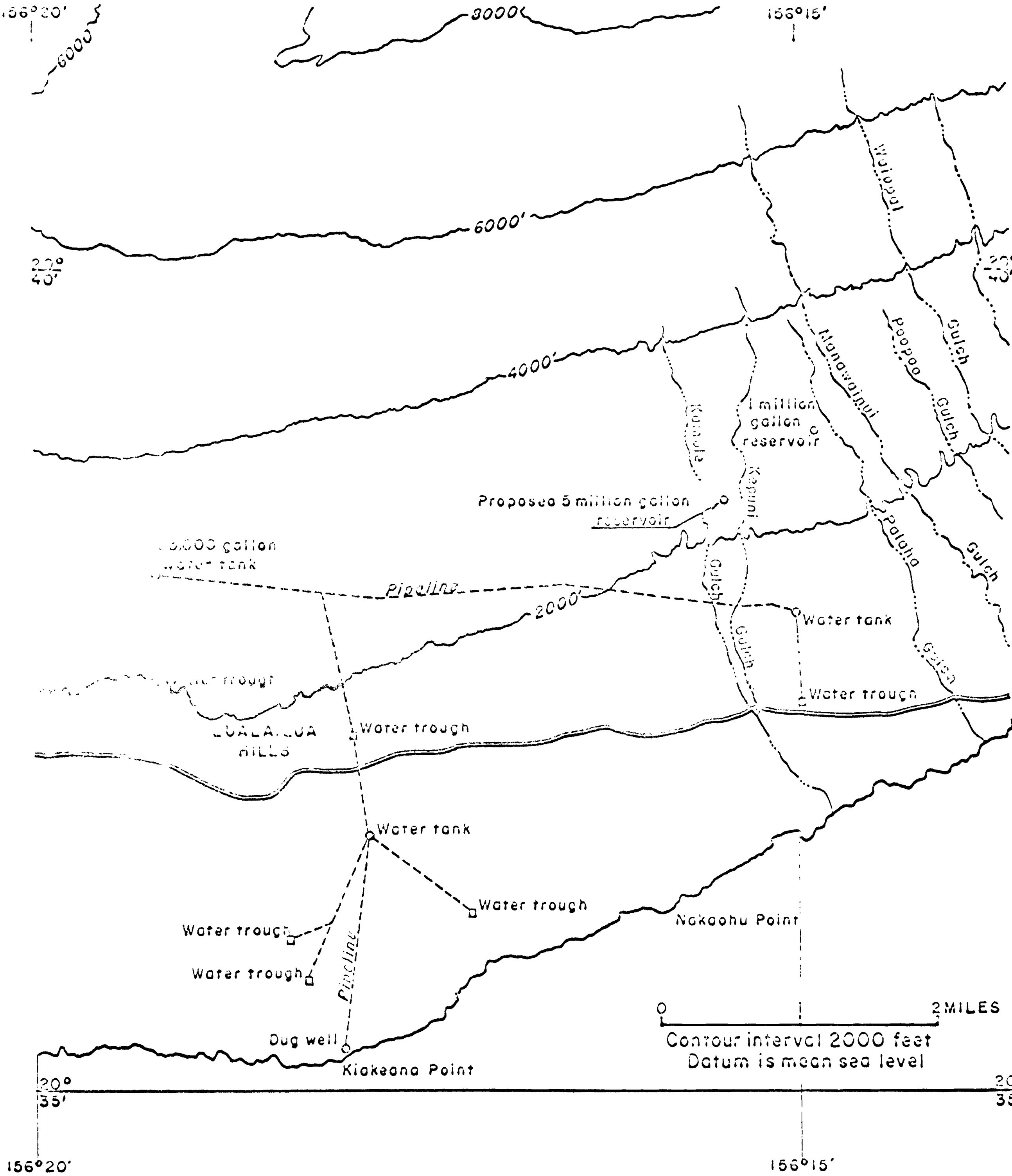


FIGURE 53. MAP SHOWING WATER DEVELOPMENT OF MAUI FACTORS RANCH

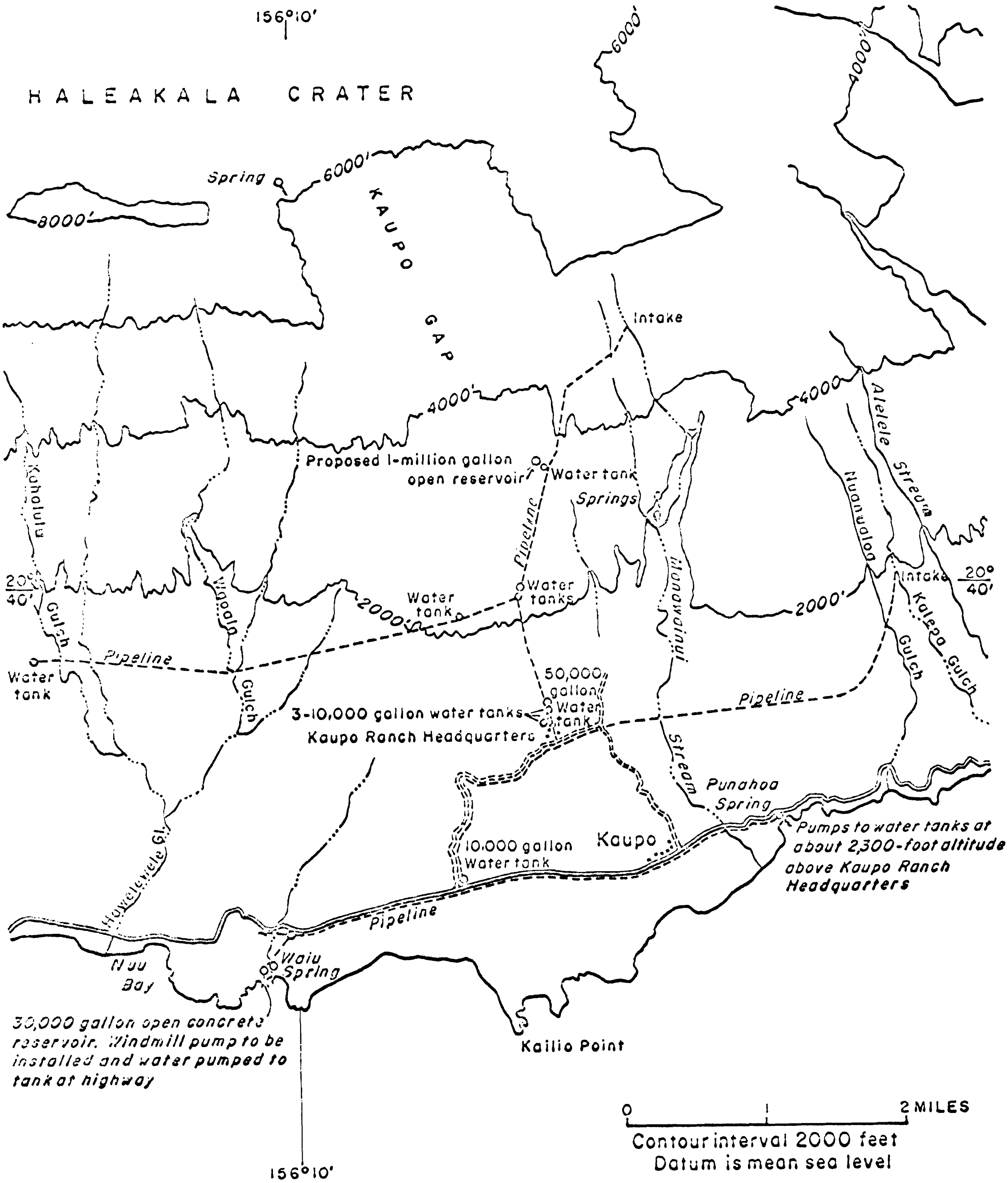


FIGURE 54. MAP SHOWING WATER DEVELOPMENT OF KAUPO RANCH

Potentials for Development

Surface Water

At considerable expense, the pipeline that diverted water from Manawainui Gulch before it was destroyed in 1938 could be relaid, but additional maintenace costs to keep it operating in view of possible landslides must also be considered.

Streams east of Wailua could possibly be diverted for small supplies, if necessary.

Ground Water

The rainfall in the eastern third of the area, which includes Kaupo Gap, is more than double that of the western part. The potential of ground-water development in these two areas should be assessed separately, in view of the large difference in rainfall.

<u>Water Budget</u>.--A rough accounting of the disposition of rainfall in the area which totals 500 mgd is:

		Mgd
Runoff	=	270
Evapotranspiration	=	145
Surplus to ground water	=	85

Owing to the sporadic nature of the rainfall input and to small ground-water storage in thin basal-water lens, much of the surplus to ground water is lost as underflow to sea.

<u>Kaupo Gap to western boundary</u>.--The prospects of obtaining good quality water in the western part is small. Even though much of the surface is highly permeable and readily absorbs the rainfall, the rainfall input is generally too low and the aquifer generally too permeable to develop much of a basal-water lens. However, with careful planning and managing, a significant supply of basal water in the chloride range of 1,500 to 3,000 mg/l is available.

<u>Hana Stream to and including Kaupo Gap</u>.--Where Hana rocks extend well below sea level, basal-water conditions will prevail, and in Kaupo Gap where Hana rocks are underlain above sea level or at shallow depths below sea level by the Kaupo mudflow, perched-water conditions are likely to prevail. In areas where less permeable Kula rocks crop out, much of the rainfall input runs off or is lost to evapotranspiration. Ground-water recharge and subsequent ground-water flow is small. Development of the streamflow supply is probably better in these areas. The development of small ground-water supplies should, however, not be ruled out. Basal-water levels are generally higher in Kula aquifer than in Hana aquifer owing to lower permeability. Because of this, wells can be drilled close to the shore and still tap fresh water. The yield of individual wells is likely to be small.

It is likely that a basal-water body is well developed in the lower end of Kipahulu Valley where permeable Hana rocks crop out and also extend to some depth below sea level.

Kahoolawe Island Subregion

Geology

Kahoolawe is a single volcanic dome composed of thin-bedded basaltic lava flows. The island was built over three rift zones, a prominent one that extends west-southward from the summit, and two less prominent, which extend eastward and northward. A caldera, about 3 miles in diameter, is at the eastern end. During the later stages of activity, the caldera was completely buried. Two groups of lavas are distinguished in the Kanapou Volcanic Series, namely, the earlier precaldera flows and the later caldera-filling lava flows. Late posterosional lavas and pyroclastics lie uncomformably on the cliffs of Kanapou Bay. The distribution of the rock units and their stratigraphic sequence are shown in figure 55.

The deep weathering of surface rocks, from 30 to 50 feet, suggests that the island is old. Overgrazing and strong winds have caused much of the top soils to blow away.

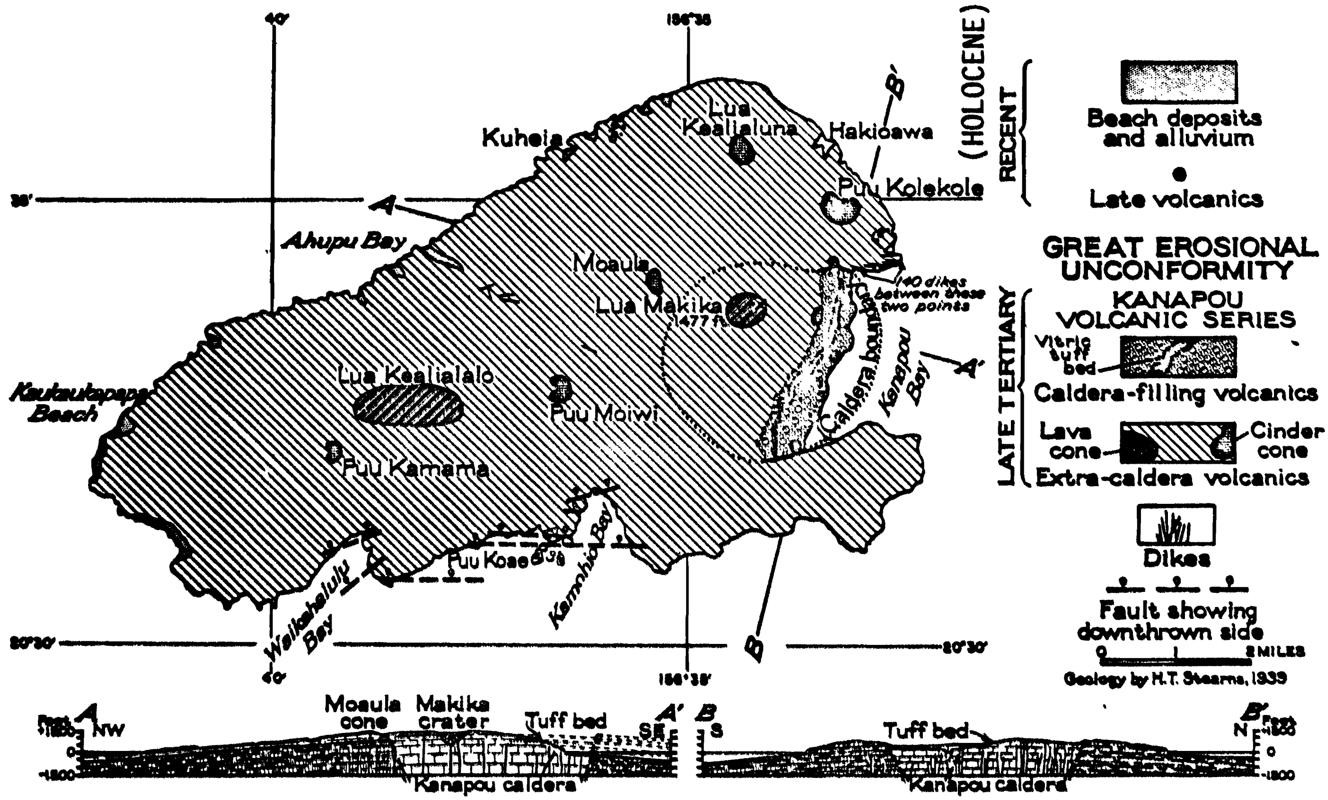


FIGURE 55. GEOLOGIC MAP OF KAHOOLAWE.

Rainfall

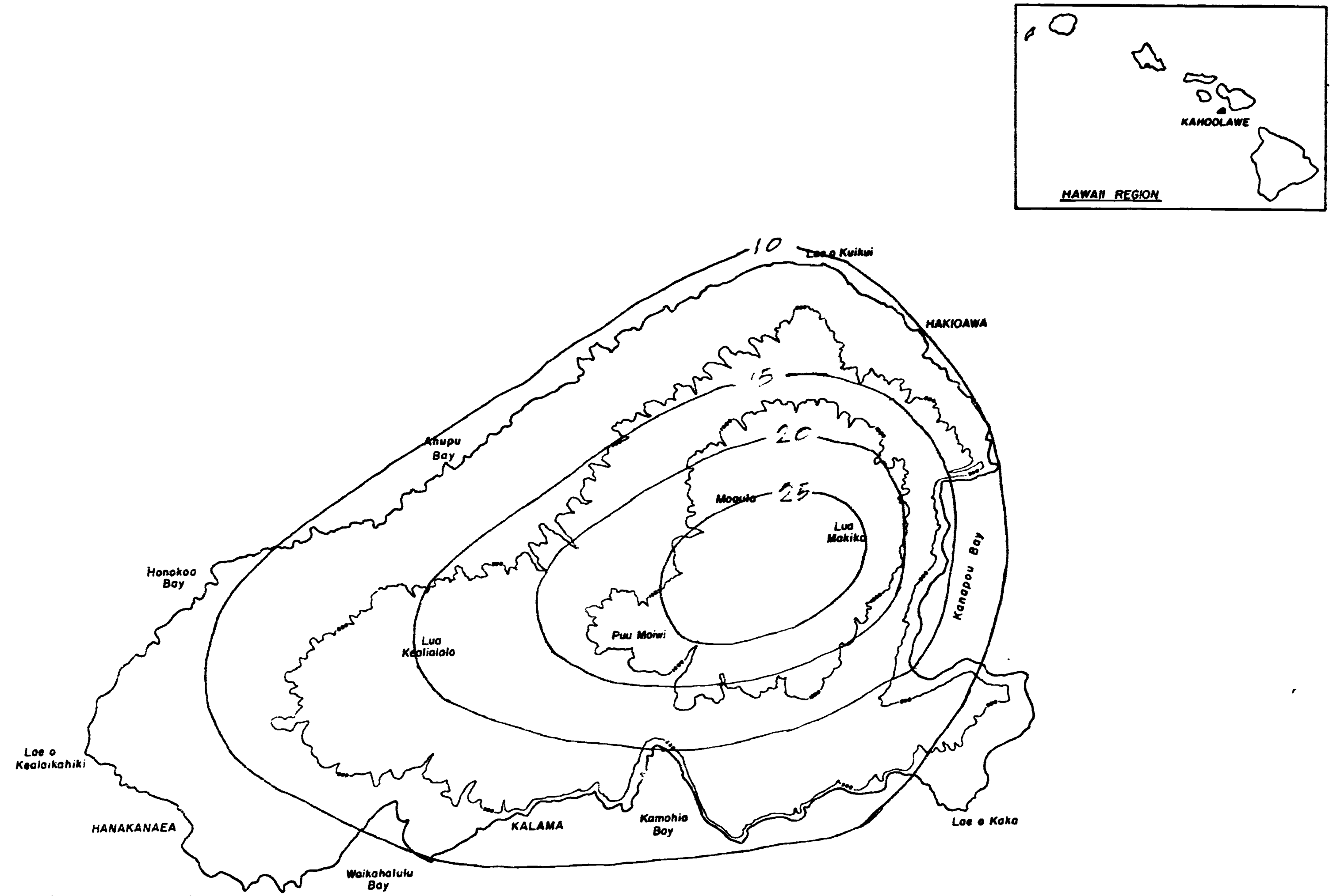
Stiff trade winds from the east blow constantly over the island but they carry little moisture because they are first deflected by Haleakala.

Average annual rainfall is about 25 inches on the summit area, and has been estimated at about 10 inches at and near the coast. Most of the rains probably result from Kona storms, and individual storms may produce as much as 4 inches of rain.

On the basis of the rainfall map shown in figure 56, rainfall on the island was computed to average about 19 inches per year, or an equivalent of 40 mgd.

Surface Water

Owing to low rainfall, there is no perennial stream on the island, and while an undetermined amount may run off directly to sea at times of Kona storms, no practical utilization of surface waters is foreseen.



RAINFALL MAP
— 25 — LINE OF EQUAL ANNUAL RAINFALL, IN INCHES

NORTH
1 0 1 2
SCALE IN MILE

SUBREGION 3
ISLAND OF KAHOOLAWE

FIGURE 56. DISTRIBUTION OF RAINFALL

Ground Water

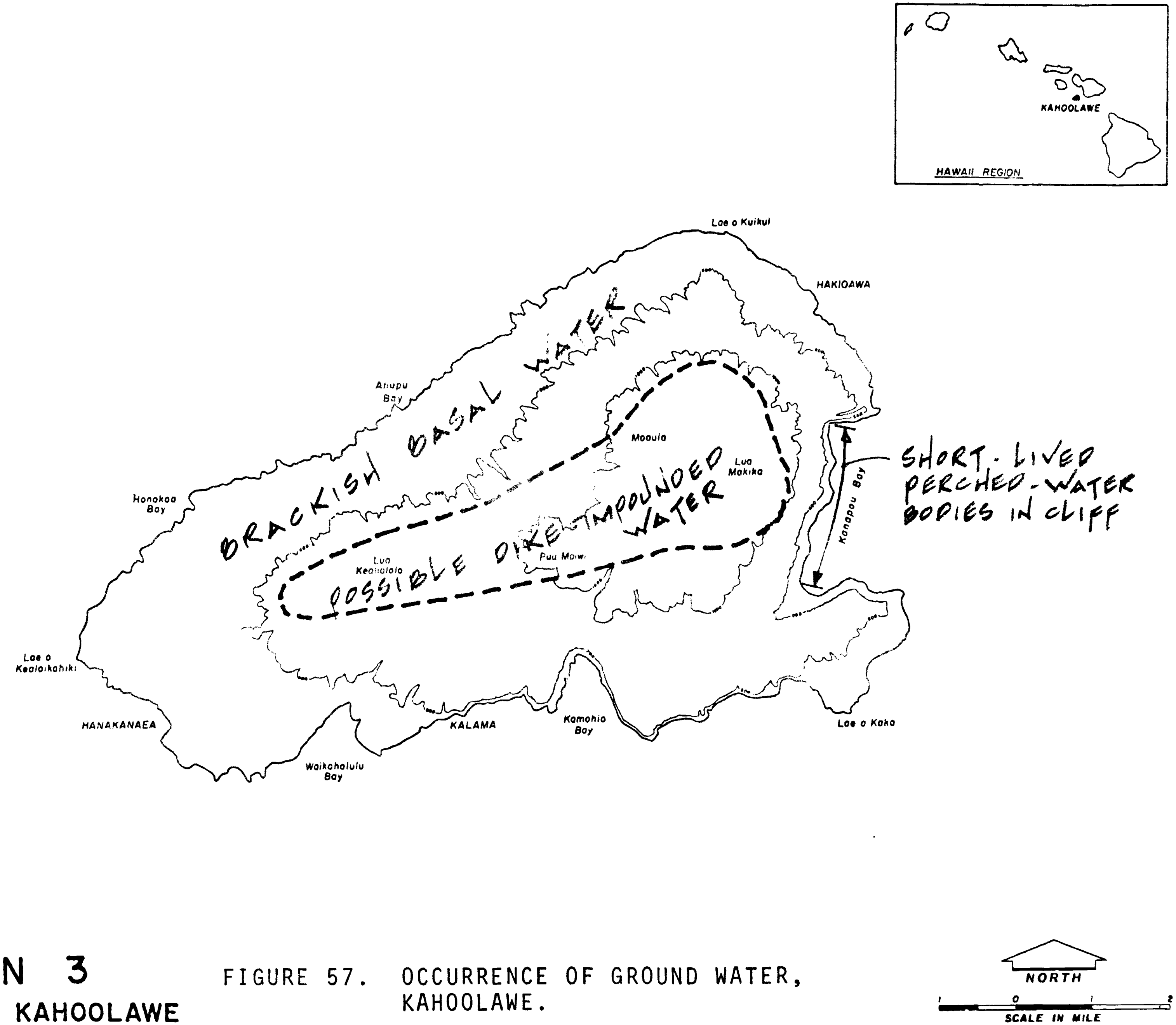
The island once supported a population of 30 to 80 persons, who probably obtained potable, brackish water from shallow wells in some of the gulches. Water suitable for animals probably existed until about 1900, but the introduction of kiawe trees have caused much of the available near-surface water to be lost to evapotranspiration.

All the wells dug yield water that is too brackish for stock except at the fairly inaccessible south side of Kanapou Bay. An electrical resistivity survey in 1939 indicated a basal-water table 1.5 feet or less above mean sea level 2 or more miles inland at an altitude of about 860 feet.

Small seeps were found in the cliff at Kanapou Bay. One was yielding about 2 gpm and the other about 4 gpm on March 7, 1939. The seeps probably issue from small dike-impounded water bodies in the caldera. Although these seeps are the only indication of the occurrence of dike-impounded water, it is likely that these water bodies occur in the rift zones.

The island is too dry to sustain perched-water bodies at or near the surface. Short-lived perched-water bodies probably prevail in the caldera area.

The probable occurrences of ground-water bodies are shown in figure 57.



SUBREGION 3
ISLAND OF KAHOOLAWE

FIGURE 57. OCCURRENCE OF GROUND WATER, KAHOOLAWE.

Quality of Water

There are no perennial streams on Kahoolawe. Runoff resulting from storms probably has chemical characteristics similar to those of rainwater. The water should have low dissolved-solids content, be slightly acidic, and probably contain measurable amounts of turbidity and bacteria.

Stearns (1940) found no sources of fresh water on the island. Pools that fill during storms do not last because of evaporation. Dug wells yield water that is too brackish for even stock use. Chloride concentrations exceeding 3,000 and 12,000 mg/l were found for two of these wells.

Present Use of Water

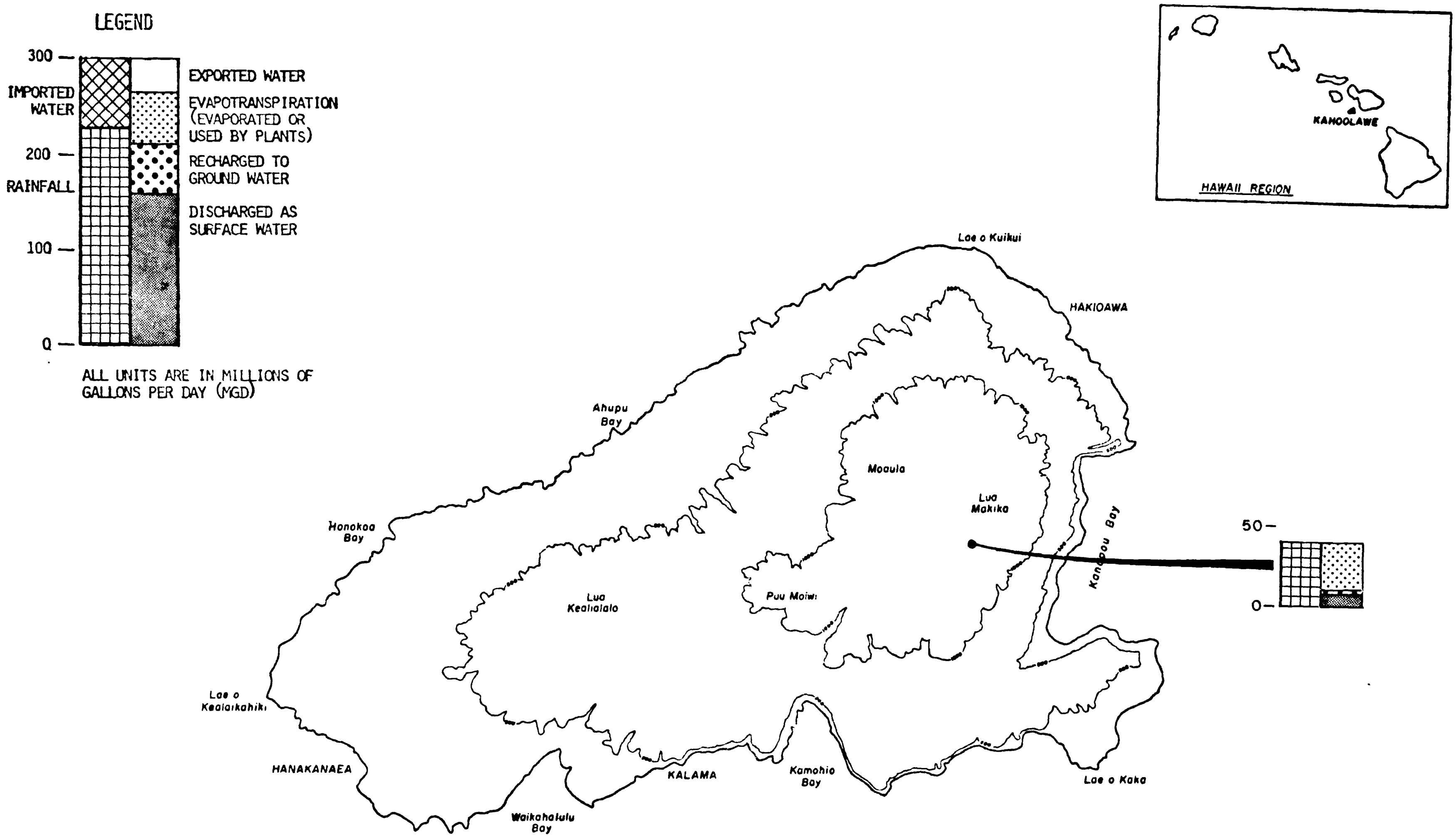
The island is used as a bombing range for airplanes. There is no one living on the island.

Potentials for Development

The rainfall input of about 40 mgd is less than 2 mgd per shoreline mile. The low ratio of rainfall input to shoreline discharge indicates little fresh basal water exists even in inland areas. Brackish water with salinities one-quarter to one-half of seawater, is probably available in significant amounts as a potential supply for desalinization plants.

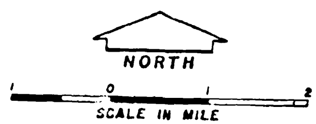
The best prospects for developing fresh water would be in the rift zones where water may have accumulated in lava flows intruded by dikes. The restriction to flow causes water to accumulate and also tends to keep seawater from intruding.

The most promising place, at the lowest altitude, is in Ahupu Gulch at an altitude of about 800 feet. A well, at 1,200 feet altitude, one-half mile east of this site, would penetrate deeper into the rift zone. The height of the water table is unknown but it may not be far above sea level because of the small recharge.



SUBREGION 3
ISLAND OF KAHOOLAWE

FIGURE 58. WATER OCCURRENCE.



Lanai Island Subregion

Geology

The island of Lanai is a shield volcano built by eruptions at the summit and along three rift zones during one period of activity. There were no secondary eruptions. The summit of the volcano collapsed to form a caldera, which was partly filled by lava flows. The present Palawa Basin, 4 miles long and 3 miles wide, is a remnant of the caldera.

The volcano was built of basaltic lava flows, ranging in thickness from 1 to 100 feet, and averaging about 20 feet. Sedimentary rocks consist of sand, alluvium, lithified dunes, and marine conglomerates. The distribution of the rocks are shown in figure

Dike and fault systems associated with the caldera collapse and rift zones are capable of impounding ground water at high levels. The major faults are shown in figure 59. Dike swarms are shown on the geologic map (fig. 60).

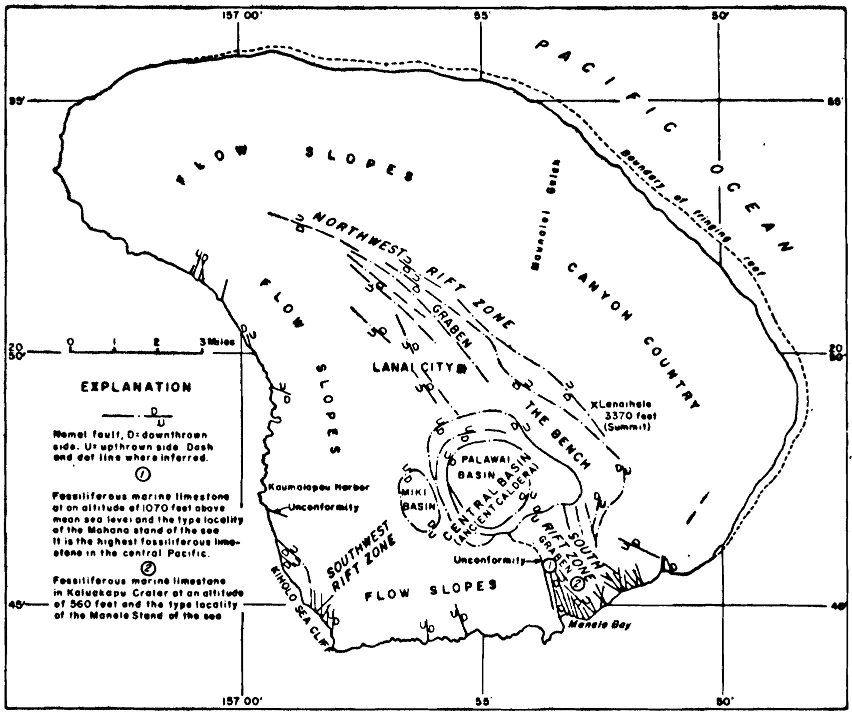


FIGURE 59. MAP OF LANAI SHOWING THE MAJOR GEOMORPHIC UNITS, FAULTS. (AFTER STEARNS, 1940)

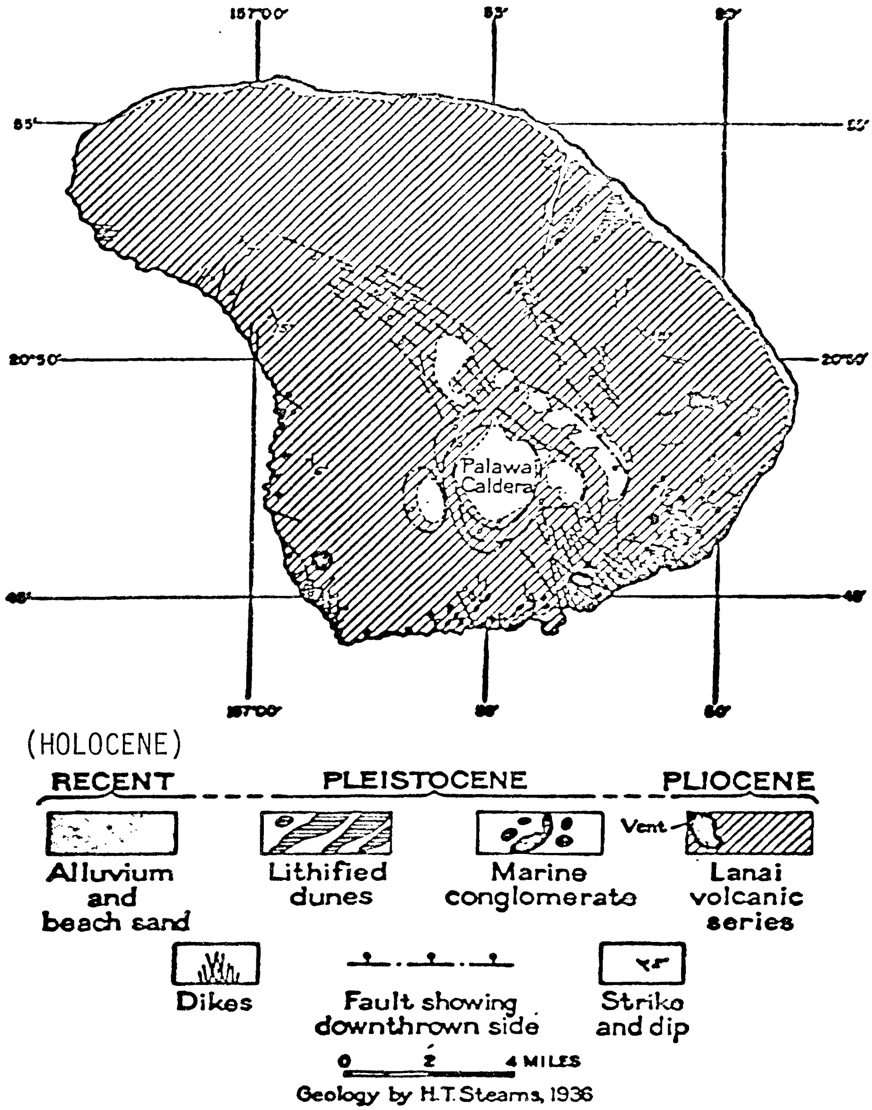


Figure 60—Geologic map of the island of Lanai.

Rainfall

The island of Lanai is dry mostly because it is sheltered in part from the trade winds by West Maui and the eastern part of Molokai.

Average annual rainfall ranges from less than 15 inches to little more than 35 inches. The annual mean, based on a rainfall map prepared by Stephen P. Bowles in 1971 for the Lanai Co., is 28 inches, the equivalent of which is 187 mgd (fig. 61).

Surface Water

Streams seldom flow except when Kona storms strike the island, which is only a few days in a year. Maunalei Gulch had apparently the only perennial stream on the island. Development of ground water by tunnels and shafts has caused this stream to become ephemeral.

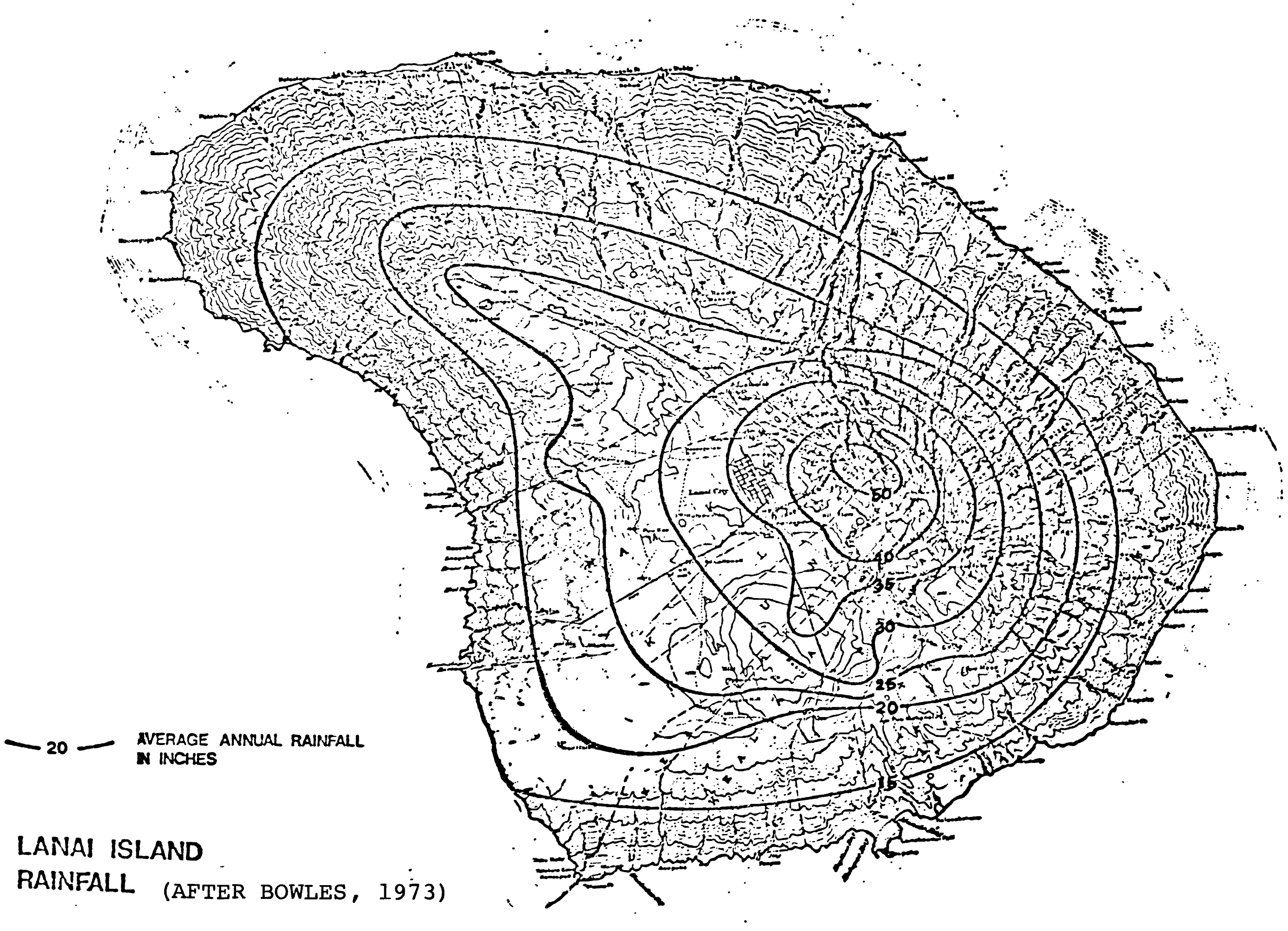


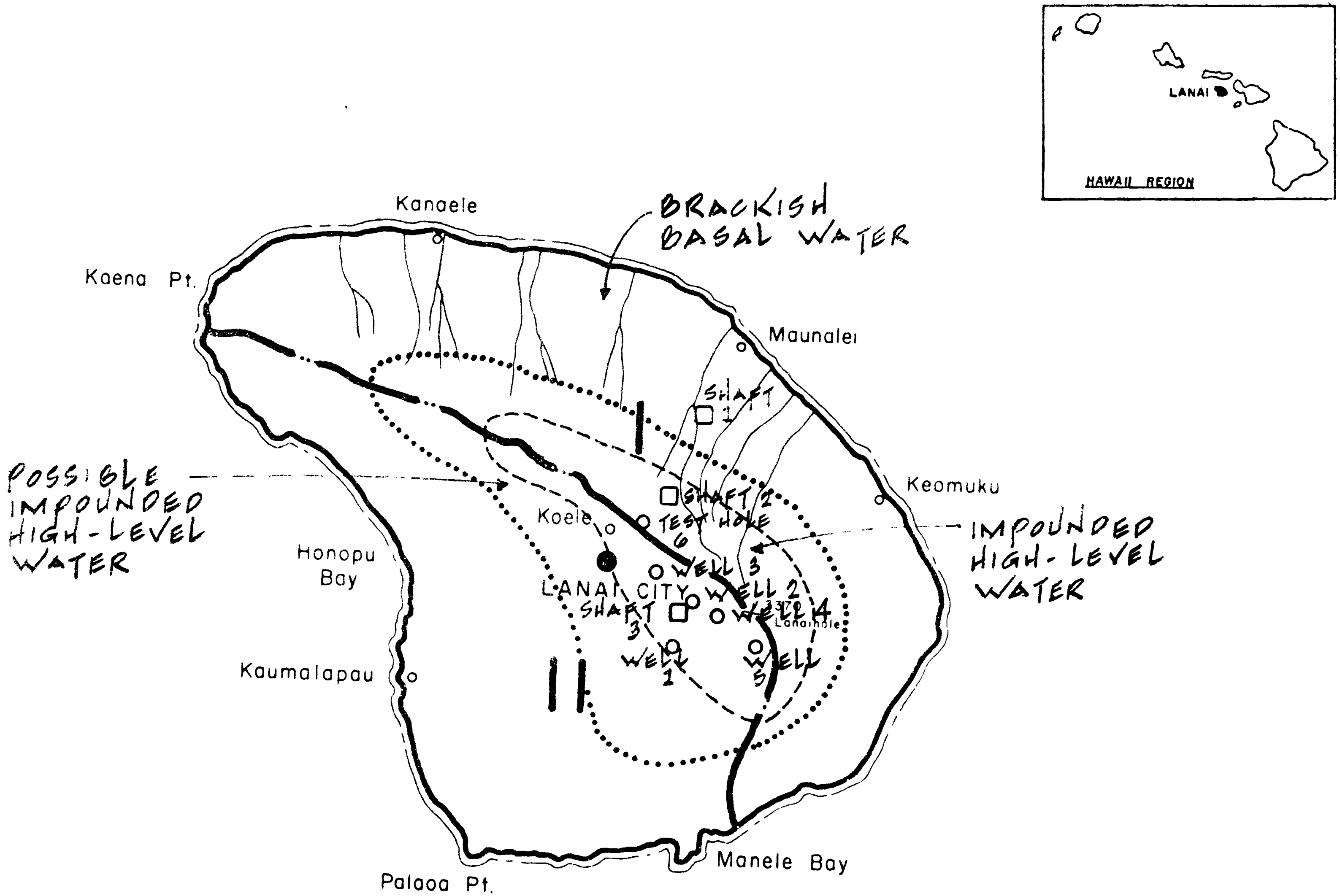
FIGURE 61. DISTRIBUTION OF MEAN ANNUAL RAINFALL.

Ground Water

The ground-water map (fig. 62) shows the occurrence of ground water and the location of the principal wells.

Basal Water

Basal water occurs in all coastal areas in a band 2 to 4 miles wide. The rainfall input of 187 mgd is roughly equivalent to a rainfall discharge of about 4 mgd per shoreline mile. Even if the ground-water discharge is 25 percent of this quantity or 1 mgd per shoreline mile, it is apparently not adequate to maintain a fresh basal lens in coastal areas. It is, however, quite likely that a significant quantity of brackish basal water (concentration greater than 500 mg/l of chloride) can be developed. The eastern and southern coasts appear to be better for development--the eastern coast owing to more rainfall, and the southern coast owing to the presence of dikes--which could channel ground water to the coast.



GROUND WATER ZONES

(AFTER BOWLES, 1973)

SUBREGION 4
ISLAND OF LANAI

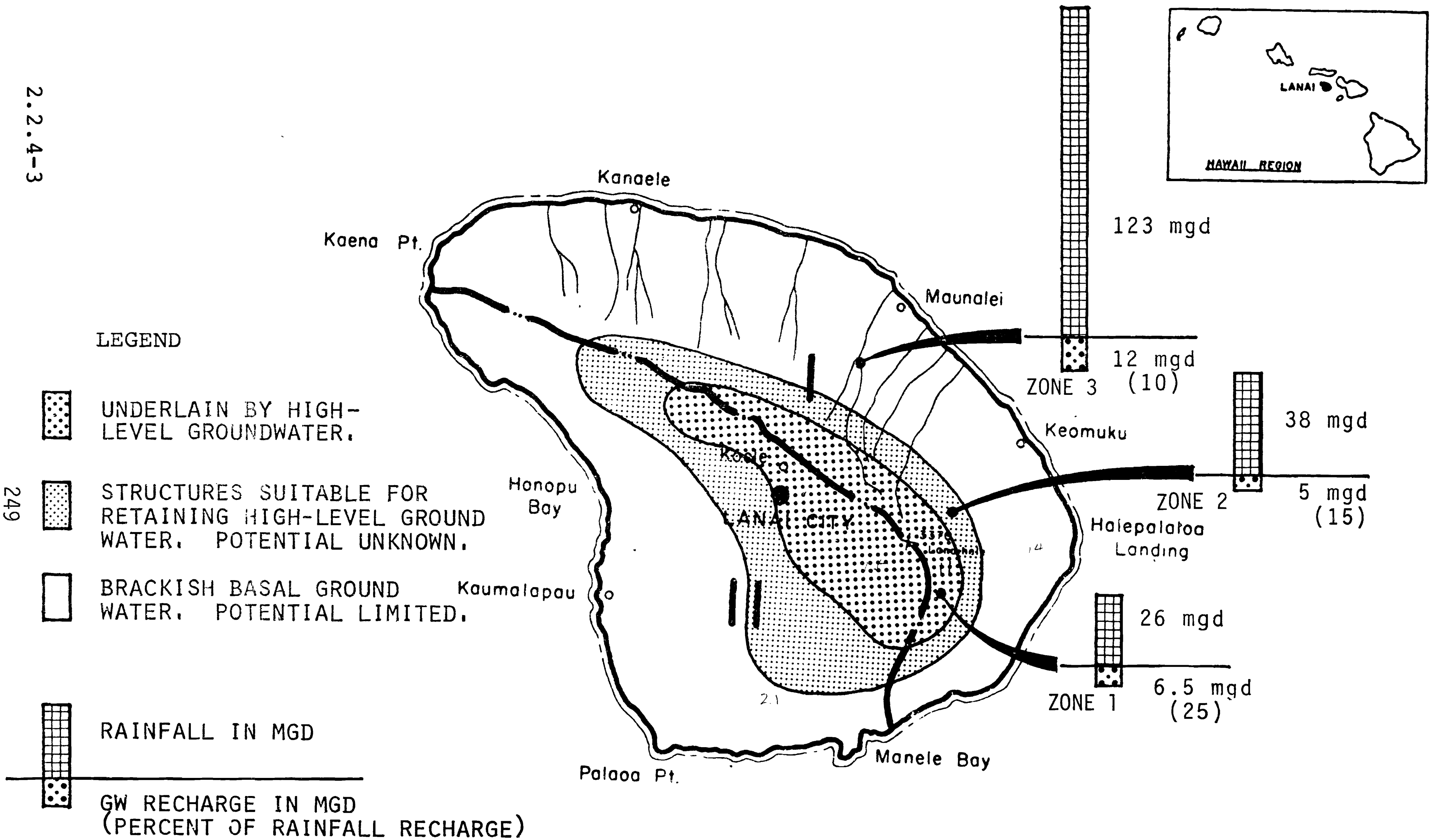
FIGURE 62. GROUND WATER MAP.

Dike-Impounded Water

High-level impounded ground water in the central part of the island is the most important water source. The water is probably impounded by dikes or faults or by a combination of both. Nearly all of the developed irrigation and domestic water comes from this source.

Water levels range from about 720 to about 1,600 feet above sea level. Investigation by Bowles (1973) shows the water body to be compartmented; water levels are step-like and differ from one compartment to another. The highest water levels underlie the topographic high, where rainfall is greatest. These compartments are interrelated, but water levels in them fluctuate according to pumpage and recharge of the compartments.

Of the estimated rainfall of 187 mgd, about 26 mgd reportedly falls in the known high-level water zone and about 38 mgd falls in the possible zone of high-level water (fig. 63). Bowles estimates that 25 percent or 6.5 mgd of the rain in the known high-level zone recharges the ground-water body. This compares with 6.4 mgd of ground-water recharge estimated by Stearns (1940).



SUBREGION 4
ISLAND OF LANAI

FIGURE 63. GENERAL LOCATION AND CAPACITY OF GROUND-WATER BODIES.

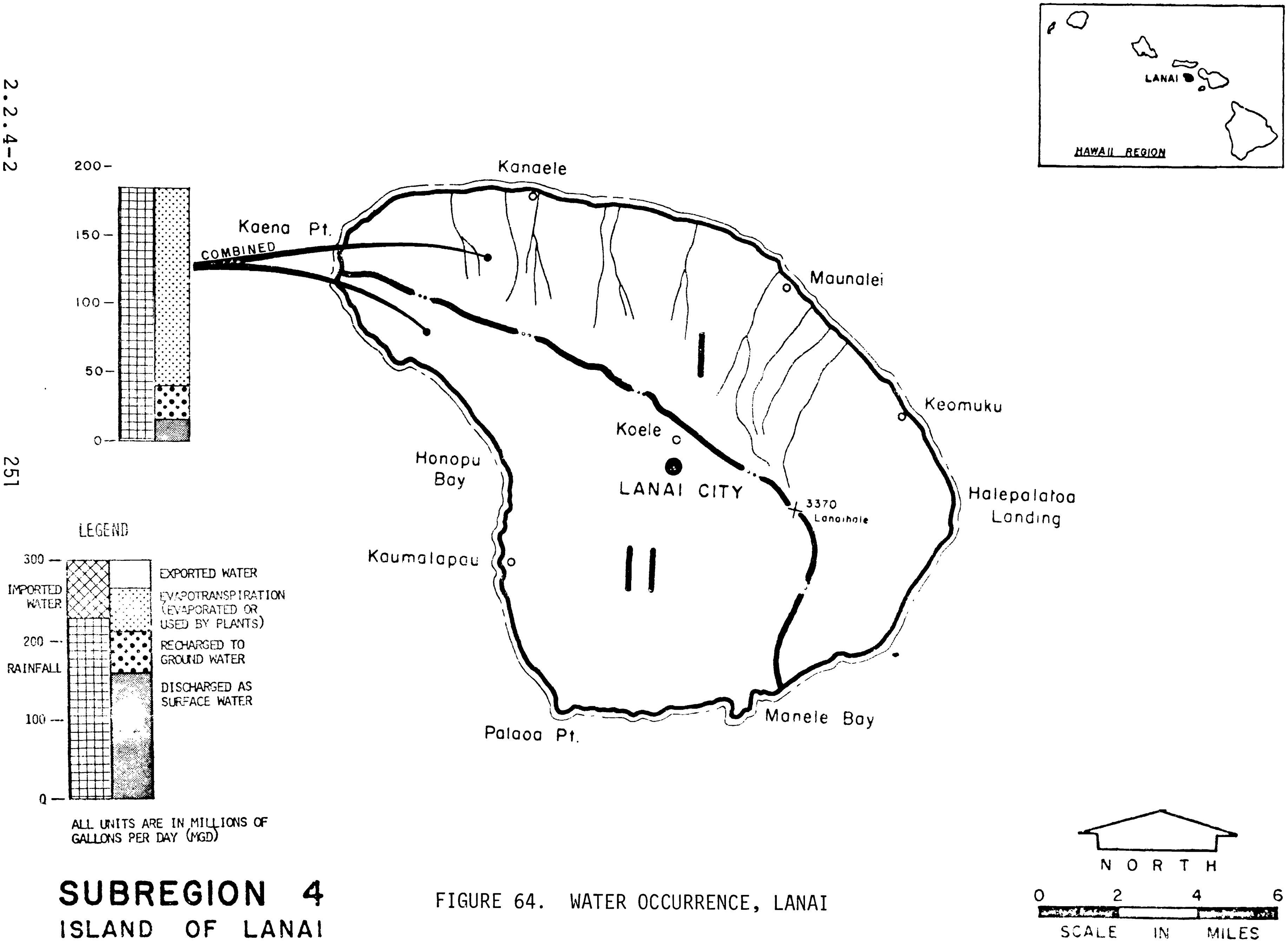
Perched Water

Perched water is scarce on Lanai. Small seeps, reportedly flowing 1 gallon per minute or less in dry areas, occur in upper Maunalei and Waiapaa Gulches.

Figure 64 shows the occurrence of water on Lanai.

Quality of Water

Lanai has no perennial streams, and surface runoff is limited to flows during storm periods. Fertilizers or other soluble salts may be leached from the cultivated fields during these storms. High runoff may also contain high turbidity and sediment loads.



SUBREGION 4
ISLAND OF LANAI

FIGURE 64. WATER OCCURRENCE, LANAI

Potable water for Lanai is developed mainly from bodies impounded by dikes or fault formations. The chemical quality of the water is excellent, and did not change significantly between 1936 and 1963, as shown by the following analyses of Maunalei Shaft No. 2 water:

	(Reported by Stearns) Avg of six samples July-Sept. 1936 (mg/l)	(DOH) Nov. 14, 1963 (mg/l)
Silica (SiO_2)	36	33
Bicarbonate (HCO_3)	94	98
Chloride (Cl)	22	34
Dissolved solids	144	188
Hardness (as $CaCO_3$)	56	78

The water is relatively free of bacteria and is being used without treatment.

Basal water along the coast is brackish, and not recommended for domestic use. Dissolved-solids concentrations range from 1,000 mg/l to nearly seawater concentration.

Present Use of Water

High-level water was first discovered in Maunalei Gulch (Shaft 2) in 1938. Subsequently, five wells and an inclined shaft were constructed between 1948 and 1961. All of the development has been in the zone of impounded high-level water shown in figure

Average annual pumpage since 1948 is 1.37 mgd, of which 1.07 mgd is for irrigation of pineapples and 0.30 mgd is for domestic supply. The quantity pumped for irrigation is highly dependent on the variations of rainfall, and has ranged as much as 500 percent. Domestic supply is steady.

Potentials for Development

Flow has been estimated at about 1 mgd per shoreline mile. A part of this flow may be recovered by careful dispersal of wells, especially in a direction parallel to the shore. Water is likely to be brackish with a chloride content generally exceeding 500 mg/l.

The estimated ground-water recharge figure of 6.5 mgd is based on long-term rainfall averages. The recharge, according to Bowles, probably varies between 2 to 10 mgd from year to year.

In order to best develop the high-level water body, its large inherent storage must be utilized advantageously. Bowles suggests that proper pump settings could allow water levels to be drawn down 100 feet or more during prolonged dry periods. This would allow more space to be restored during wetter periods.

In most instances, perched water is too scarce and too sparse to be considered as an important source of water.

Molokai Island Subregion

Windward Molokai (Area I)

Geology

Windward Molokai comprises the caldera and northern slopes of ancient east Molokai volcano. Pelekunu and Wailau Valleys have cut deeply into the central core of the volcano, as much as 4,000 feet, exposing the dike complex and caldera region, older thin-bedded basalt flank flows, and younger andesite flows which cap the basalt flows. Waikolu and Halawa Valleys on the west and east also have cut deeply into the mass of the volcano. Generally, the basalt flows are permeable and serve as the chief aquifers, whereas the dense and impermeable capping andesite lavas form swampy lands on relatively flat summit slopes.

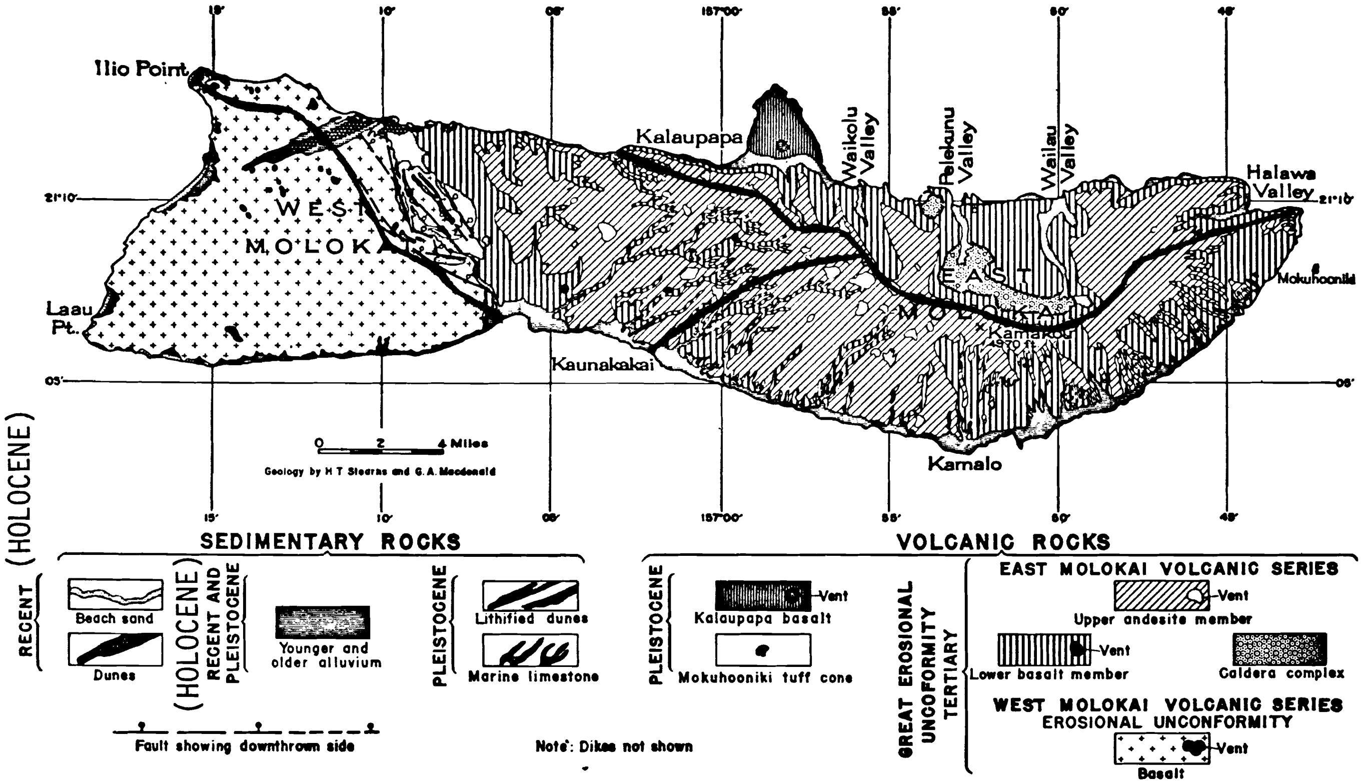


FIGURE 65. **Geologic map of the island of Molokai.**

Rainfall

Areal Distribution

Windward Molokai coincidentally embraces the island's single major orographic rainfall belt which receives an estimated 200 inches of rainfall annually. Although very little gaging records are available, the average annual rainfall is estimated to range from 40 inches over the lower slopes to as much as 200 inches over the headwater slopes of Pelekunu and Wailau Valleys. An estimated 230 mgd of rain falls during an average year in the windward area.

Seasonal Variations

The pattern of rainstorms and droughts is undoubtedly typical of windward valleys and slopes of the other islands of the State. Although rainfall records are lacking, long-term stream gaging records are available and should provide some correlative information.

Evapotranspiration

No records on evapotranspiration are available. Although studies in other similar areas of the State suggest that evapotranspiration amounts to about one-third of the total rainfall, it very possibly is significantly less than that in the windward Molokai area. Estimating this water budget for windward Molokai is considered very speculative.

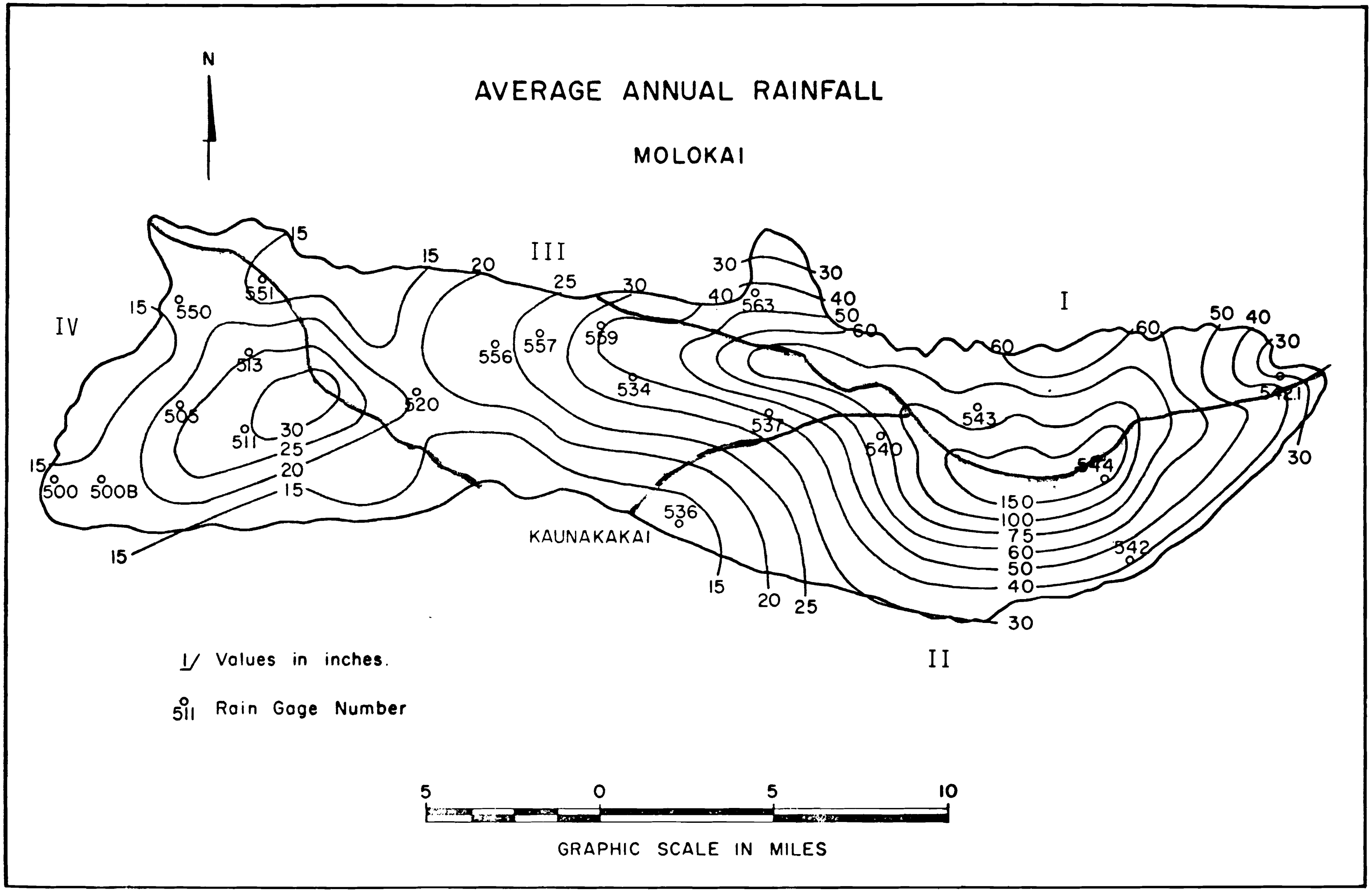


FIGURE 66. AREAL DISTRIBUTION OF RAINFALL, MOLOKAI.

Surface Water

Areal Distribution

Virtually all surface waters on Molokai occur in windward Molokai, flowing northward and eastward into the ocean. Numerous high-level springs issuing from the dike complex and seepage from the mountain swamplands account for most of the perennial low flows. It is estimated that the five major streams of windward Molokai discharge an average of 150 mgd into the ocean. These streams are the Waikolu, Pelekunu, Wailau, Papalaua, and Halawa Streams. Of the total 150 mgd, an estimated 110 mgd is discharged from the mouths of Waikolu, Pelekunu, and Wailau Streams. These total discharge estimates are believed to be conservative, inasmuch as numerous small streams have not been considered, nor has all of the gain in streamflow between gaging stations and the ocean been accounted for.

Seasonal Variations

All of the perennial streams have characteristically flashy flows due to steep gradients, narrow channels and highly variable rainfall intensities. Daily hydrographs of windward streams show extremely sharp peaks, representing almost instantaneous concentrations of flow in comparison to the average daily flow. For example, Pulena Stream in Wailau Valley had a peak discharge rate of 11,400 mgd on March 3, 1943, but the day's average flow was only 225 mgd. The rapid peak discharges of the windward Molokai streams are probably due largely to the fact that the dike complex aquifers cut by the streams are saturated. Saturation is, in turn, suggested by the fact that most streams are gaining streams.

Ground Water

Basal Water

Although basal ground water in windward Molokai has been totally unexplored by drilling, it undoubtedly occurs because rainfall is so abundant and it undoubtedly could be developed in the lower elevation of all of the valleys from Waikolu to Halawa Valley. However, the economic feasibility of utilizing the basal-water supply is extremely limited due to the inaccessibility of the windward valleys. The basal lens probably is thick and fresh right up to the shoreline, as it is along the southern Hamakua coast on the island of Hawaii.

Dike Water

High-level dike water occurs extensively in the central interior of windward Molokai in a belt 2 to 3 miles wide and 12 miles long, from east to west. The western limit of dike-water occurrence above 1,000-foot elevation was located by the Molokai tunnel approximately 2 miles west of Waikolu Stream. The streams of Waikolu, Pelekunu, and Wailau Valleys have their low perennial flows to dike-water drainage between elevations of 500 and 3,000 feet. The Molokai tunnel develops about 2 mgd and dike water could also be developed by tunnels in Pelekunu and Wailau Valleys. Dike water in the windward Molokai area has been developed only in Waikolu Valley by the Molokai tunnel and three drilled wells.

Perched Water

Perched ground water occurs in the high-level swamplands on andesite bedrock at elevations of 3,000 to 4,000 feet, above Waikolu, Pelekunu and Halawa Valleys. These perched ground-water sources have not been evaluated and are small, scattered, inaccessible, and insignificant as major water supplies.

Water Quality

Stream Water

The surface waters of windward Molokai are of excellent quality for irrigation purposes. The typical total dissolved solids content is about 60 mg/l, well below the tolerable limits of most plants and the sodium adsorption ratio is a very low 0.44. Chemically, it is safe for domestic use. However, during periods of storm runoff, the water becomes turbid brown in color with an organic taste. Bacteriologically, the water occasionally shows the presence of organisms of the coliform group in amounts exceeding the limits of health standards.

Ground Water

Dike complex and basal lens ground water in the windward Molokai are of excellent quality, chemically and physically. The dike water in Waikolu Valley has a chloride content of 12 mg/l.

Present Use of Water

Surface Water

Surface water in windward Molokai is virtually undeveloped, except for Waikolu Valley where the Molokai tunnel system diverts by gravity flow water at an elevation of 1,000 feet and by pumps at an elevation of 700 feet. Kalaupapa is supplied by a surface-water intake at about 520-foot elevation in Waikolu Stream. A small surface-water intake in Halawa Stream supplies a few homes in Halawa Valley.

Ground Water

Except for Waikolu Valley, no ground-water sources have been developed or utilized in windward Molokai.

Potentials for Development

Windward Molokai receives 41 percent of the total rainfall on the island of Molokai or an estimated 230 mgd. Of this amount, an estimated 150 mgd is lost to the ocean as discharge from five principal streams in the area, leaving a net 80 million gallons per day available for unaccounted evapotranspiration and recharge to the ground-water basin. The large amount of runoff (65 percent of available rainfall) occurs probably because the windward valleys dissect a fully saturated dike complex, which has much less opportunity for recharge.

The surface-water resources of windward Molokai offer the greatest potential for meeting the bulk of the future water needs of the island, especially since the Molokai tunnel has a maximum capacity of transporting 40 mgd from the windward area through the mountains to the western half of the island.

Hydrologic studies have been made to determine the available surface-water supplies that could be diverted from six streams in Waikolu, Pelekunu, and Wailau Valleys by gravity flow into the existing Molokai tunnel system. The estimates to the nearest mgd are shown below:

Available and Divertible Surface-Water Supply

Valley	Available Flow (mgd)	Divertible Flow (mgd)
Waikolu	6	4
Pelekunu	17	12
Wailau	22	16

In addition to the divertible surface water that would be available at the 1,000-foot elevation, high-level dike-confined ground water of undetermined amount would also be developable in tunneling through to Pelekunu and Wailau Valleys and by constructing selected lateral infiltration tunnels.

Basal ground water in windward Molokai, although probably abundant, has little potential for feasible development or use in other parts of the island because it would not only require remote facilities and power transmission, but also would have to be pumped and lifted high over the mountains or the Molokai tunnel at an elevation of 1,000 feet.

Leeward Molokai (Areas II, III, and IV)

Geology

Leeward Molokai includes the west Molokai volcanic dome and the south-southwestern leeward slopes of the east Molokai volcanic dome. Deeply weathered reddish brown residually weathered volcanic soils on gentle to rolling slopes characterize the western half of leeward Molokai. The eastern half consists of the deeply gullied and eroded southern flanks of the east Molokai volcano.

Rainfall

Areal Distribution

Areas III and IV which constitutes more than two-thirds of the leeward Molokai area have an annual rainfall average of only 15 to 30 inches, and very little, if any, of this rainfall which amounts to a 160 mgd, is assumed available for ground-water recharge through deep percolation. Over the remaining leeward Molokai area (Area II), which comprises the southern slopes of east Molokai mountain, the average annual rainfall diminishes drastically from about 150 inches at elevations of 3,000 to 4,000 feet to 30 inches along the southern coast, a distance of only 4 to 5 miles. Volume-wise, the average annual rainfall over this portion of leeward Molokai is 175 mgd. Of this amount, an undetermined amount recharges and maintains the thin basal lens along the southeastern coast of Molokai.

In summary, the island of Molokai receives an estimated average 565 mgd of rainfall annually. Of this amount, 230 mgd falls in the windward Molokai area and 335 million gallons per day falls in the leeward Molokai area. Of the 335 mgd leeward Molokai total, an estimated 160 mgd falls annually over west and central Molokai where the basal lens is entirely brackish. The remaining 175 mgd that falls on the southern slopes of east Molokai provide an undetermined amount of recharge to maintain a fresh, but thin basal lens along the southeastern coast.

Seasonal Variations

Rainfall in leeward Molokai is largely orographically produced by the prevailing trade winds; however, a small part is contributed by cyclonic storms during the winter months. Kona rains produce flashy, rapid runoff and commonly produce flooding in the low-lying coastal areas. Periods of drought do occur occasionally but their effects are not greatly noticeable because much of the leeward Molokai area is normally dry with about 20 to 30 inches of rainfall a year.

Surface Water

Areal Distribution

No major perennial surface-water flows exist in the leeward Molokai area. A few small springs fed by perched ground water do occur in the high slopes east-northeast of Kualapuu at elevations of 2,000 to 3,000 feet. A few small streams have almost perennial flows at the southeastern end of the island where rainfall averages 75 to 100 inches. Elsewhere, in the leeward area, the gulches and stream channels have only intermittent flows, most noticeable during periods of cyclonic storms.

Ground Water

Basal Water

The basal lens which underlies the leeward Molokai area is entirely brackish and thin beneath west and central Molokai. Three deep wells at Kualapuu indicate that the basal lens becomes fresh with a head of about 10 feet above sea level just east of Kualapuu.

The west Molokai basal lens north of Mauna Loa village has a head of about 5 feet but a high salinity of 2,900 mg/l chlorides. A test well near the Molokai Airport shows that the basal lens beneath central Molokai has a head of about 5 feet and a salinity of over 600 mg/l chloride.

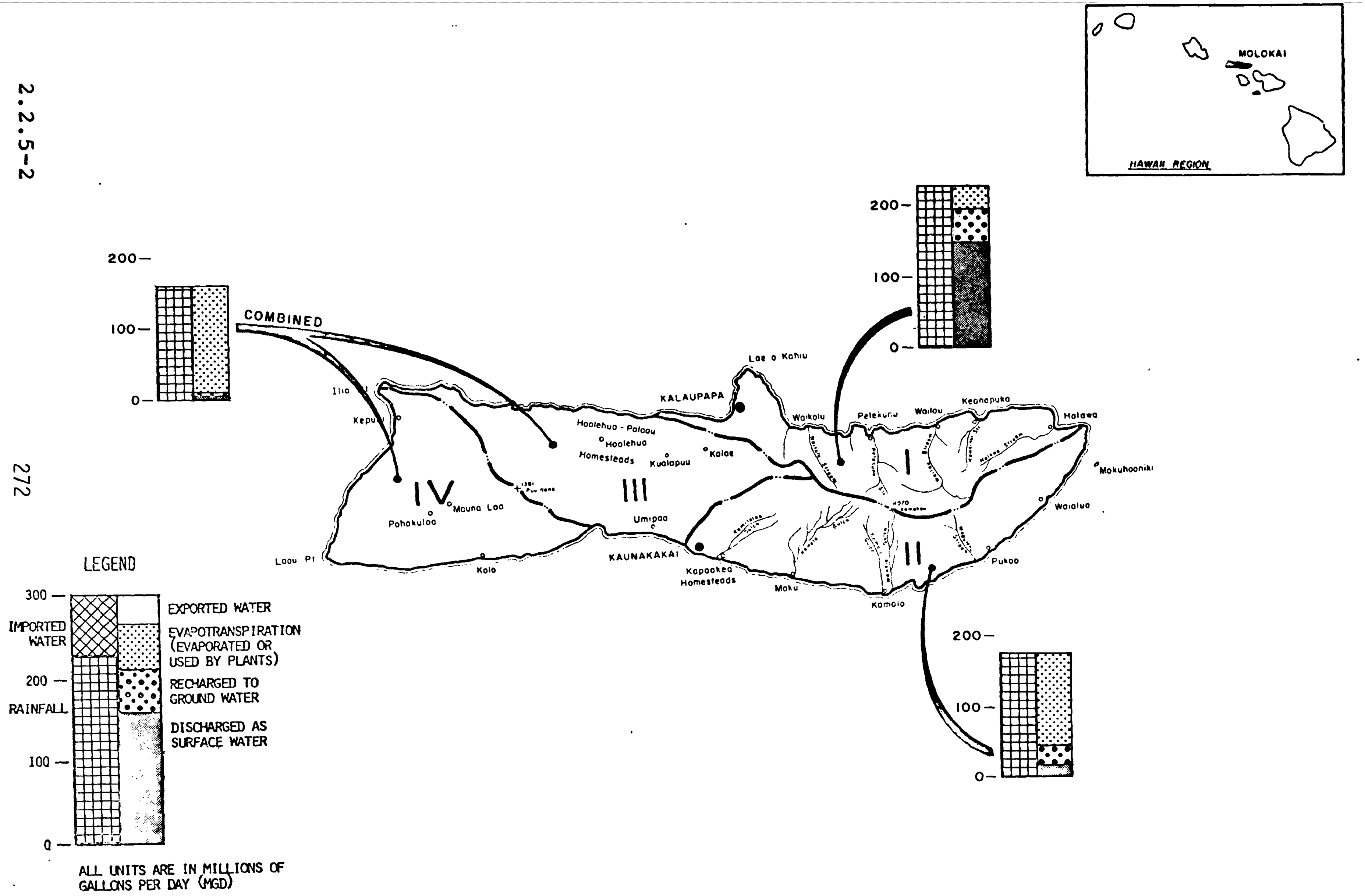
The coastal basal lens becomes fresher east of central Molokai. At central Molokai, the coastal basal lens has a salinity of 1,000 mg/l chlorides; at Kaunakakai, 600 mg/l chlorides; and at Kawela, less than 100 mg/l chlorides. From Kawela eastward to Kamalo, the basal lens is fresh but sensitive to salt-water intrusion when pumped, but farther east at Ualapue, it is much less sensitive. Two or 3 miles inland from the coast, the basal lens probably is thicker and much less sensitive to pumping; however, the rapidly rising slopes of east Molokai make it accessible only from undesirably high elevations.

Dike-Impounded Water

Dike water undoubtedly occurs beneath the interior part of east Molokai, but lies at economically inaccessible depths because no valleys have eroded deeply enough to expose it, as in the windward Molokai. Only in Mapulehu Valley, the most deeply eroded on the southern slopes of east Molokai, have a few dikes been exposed and dike-complex water might be reached at economical depths of drilling.

Perched Water

Perched ground water occurs in two principal areas--in the summit headwater region of Manawainui and Kaunakakai gulches at elevations of 1,700 feet and 4,000 feet, respectively. These sources presently supply the communities of Kalae and Mauna Loa.



SUBREGION 5
ISLAND OF MOLOKAI

FIGURE 67. WATER OCCURRENCE, MOLOKAI.

Table 15. Disposition of Rainfall

Island of Molokai
(Units of mgd)

Area	Rainfall	Evapotranspiration	Runoff	Ground-water flux
I	230	30	150	50
II	175	125	15	35
III and IV	160	150	5	5

Water Quality

Stream Water

Molokai's perennial streams discharge excellent water into the ocean. The water has low mineral content and is chemically suitable for most uses. The average dissolved-solids content is 59 mg/l. The water is very soft; average hardness concentration is 19 mg/l. The range and average concentrations of dissolved solids, hardness, chloride, and silica for selected Molokai streams are shown in figures 67 through 70.

Waikolu Stream water diverted into Kualapuu Reservoir is suitable for irrigation. Accumulated algae and slimy organisms within the reservoir can limit the use of the water. Unless these organisms are filtered out, they could flocculate fertilizer materials and clog sprinkler heads.

Ground Water

Ground water in the southern coastal areas of eastern Molokai is good; dissolved-solids and chloride contents of well waters from the basal aquifer are within the recommended drinking water standards.

Ground water in the western and central parts of Molokai has high-chloride and dissolved-solids contents. Low rainfall and seawater intrusion contribute to the poor quality of ground water.

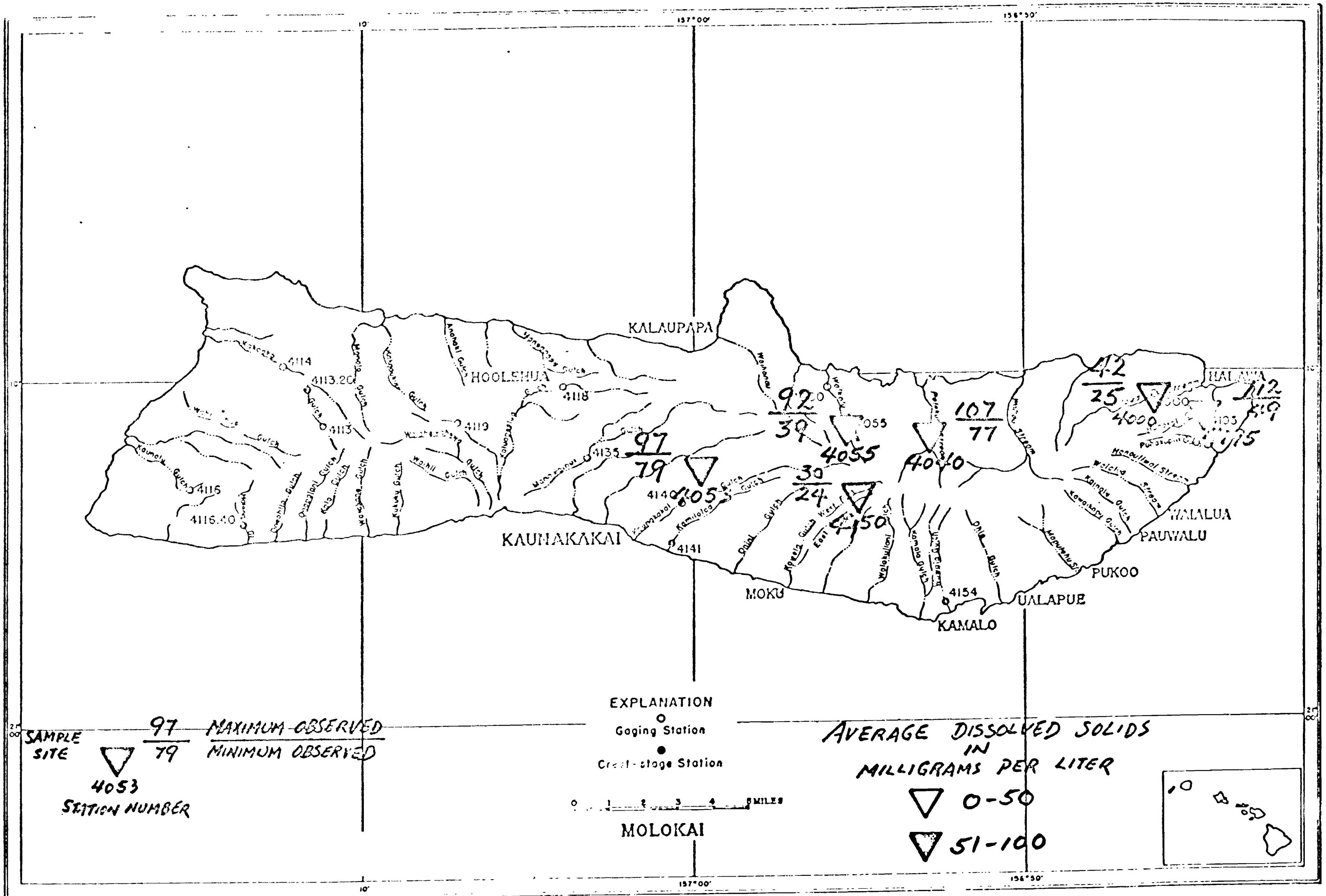


FIGURE 68. RANGE AND AVERAGE DISSOLVED-SOLIDS CONCENTRATION IN SELECTED STREAMS

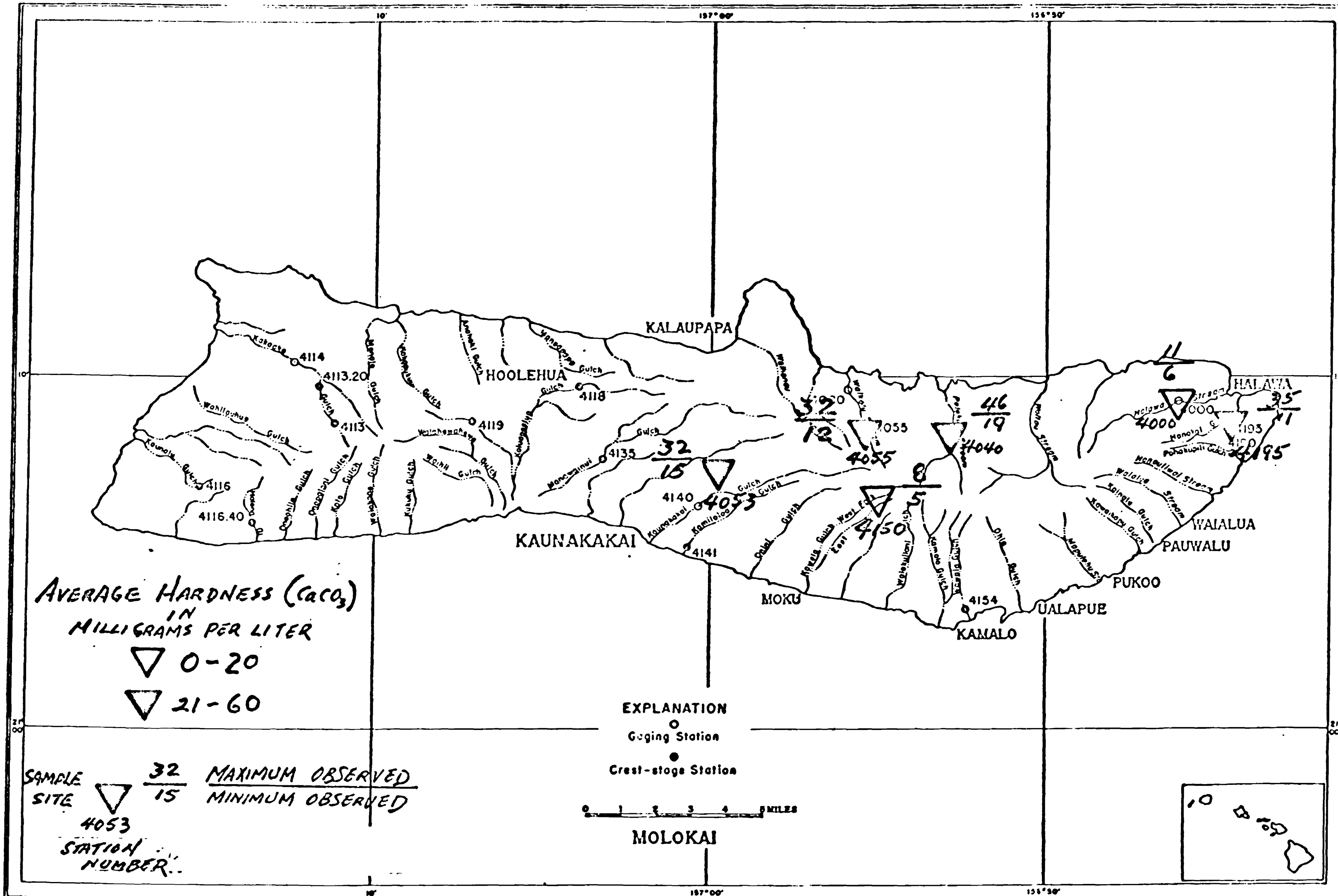


FIGURE 69. RANGE AND AVERAGE HARDNESS CONCENTRATION IN SELECTED STREAMS

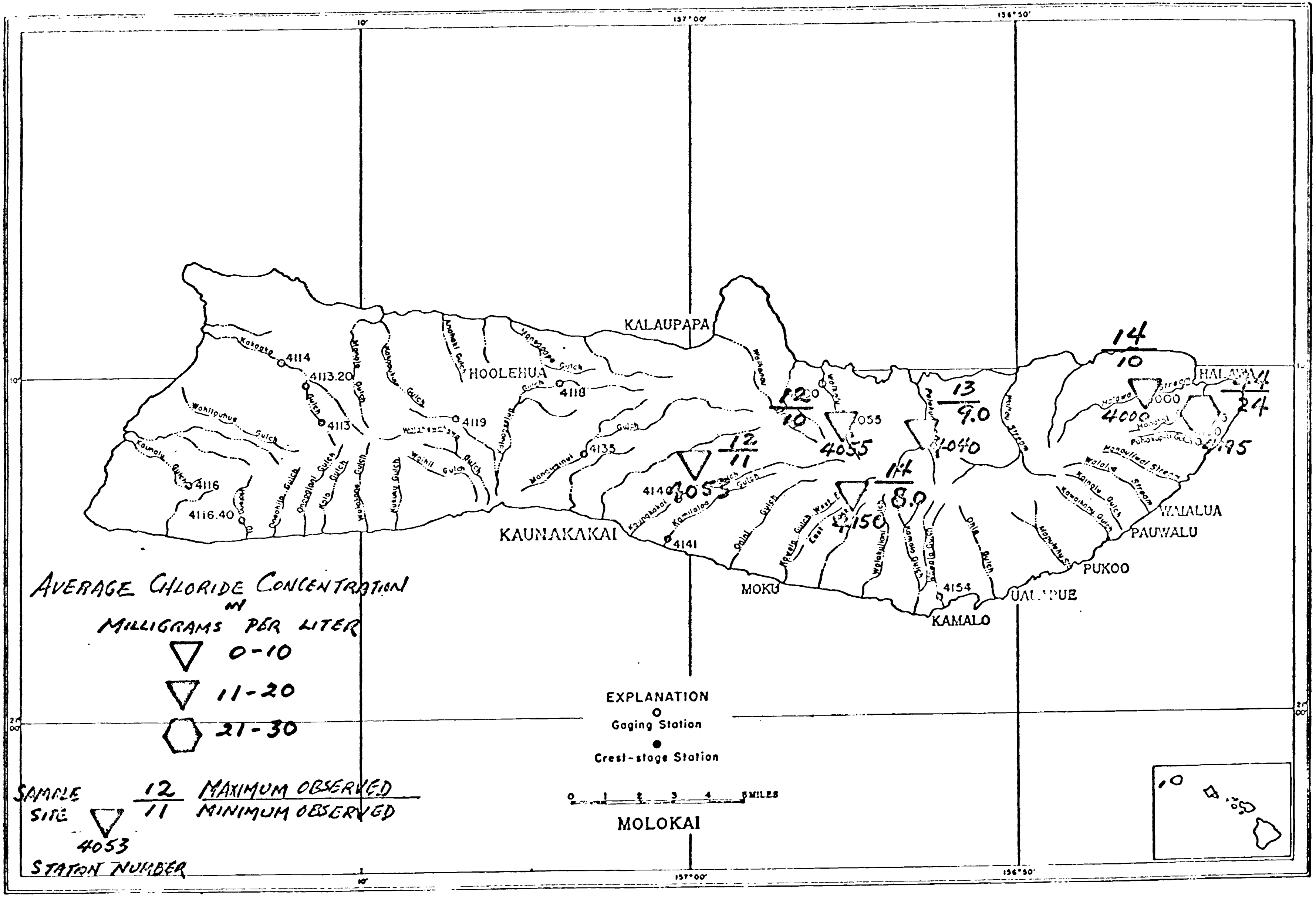


FIGURE 70. RANGE AND AVERAGE CHLORIDE CONCENTRATION IN SELECTED STREAMS

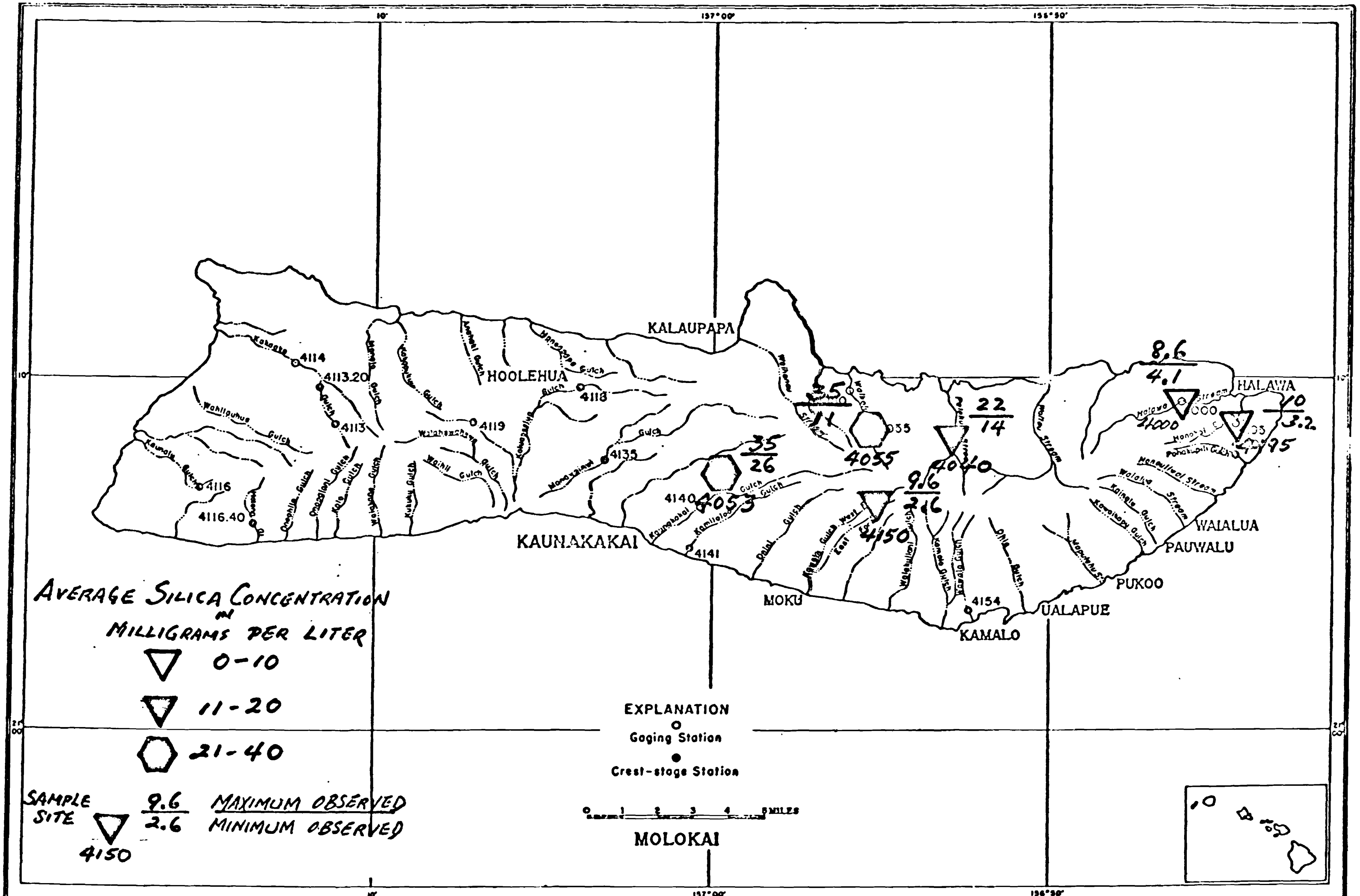


FIGURE 71. RANGE AND AVERAGE SILICA CONCENTRATION IN SELECTED STREAMS

Present Use of Water

Surface Water

The Department of Hawaiian Home Lands maintains a surface-water supply for its central Molokai homesteads of Hoolehua and Kalanaanaole-Kalanianaole west of Kaunakakai from Waihanau Stream and Kamiloloa gulch in the upper western slopes of east Molokai and also from a deep basal-water well in central Molokai.

Molokai Ranch, Ltd., also develops surface water from a number of headwater streams in the western summit slopes of east Molokai.

Ground Water

The southeastern coast of Molokai is served by County basal-lens water sources at Kawela and Ualapue. At the present time (1974), the only immediate plans for developing additional ground water in leeward Molokai is at Ualapue by the County.

Potentials for Development

There are no potential for developing new surface-water supplies in the leeward Molokai area. No potential exists for fresh ground-water development in west and central Molokai because the basal lens is entirely brackish, but additional brackish-water sources for irrigation is possible in south-central Molokai at low elevations where the basal lens can be economically reached. Fresh basal-lens water exists east of Kualapuu, but is accessible only at depths of 1,000 feet or more. Because the required deep-well facilities and pumping lift would be expensive, little potential exists for developing the interior basal lens when compared to other available water sources. The greatest potential for additional ground-water development lies east of Ualapue from the coastal basal lens which can be easily reached by shallow- to moderate-depth wells to serve local needs. The County presently utilizes surface water from the Molokai tunnel to serve Molokai's principal community of Kaunakakai.

Oahu Island Subregion

Geology

The island of Oahu, about 604 square miles in area, developed through the building and coalescence of two shield volcanoes--Waianae volcano, forming the western part of the island, and Koolau volcano, forming the eastern part. The initial phase of mountain building ended and a period of quiescence followed, during which time the volcanoes were deeply eroded. Waianae volcano became dormant before Koolau, and westward-dipping flows of the Koolau Volcanic Series overlapped the eroded slope of the Waianae shield in the central part of the island.

Volcanism resumed in the southeastern end of the Koolau Range, leaving several intravalley lava flows, cinder cones, and many tuff cones. This activity produced the rocks of the Honolulu Volcanic Series. The rocks are confined to relatively small scattered exposures.

The Koolau volcano is composed chiefly of highly permeable basaltic lava flows, which make up the bulk of the Koolau Range. The less permeable andesitic veneer common to most Hawaiian volcanoes is absent, and this makes the Koolau Range a highly permeable rock mass. In contrast, much of the older Waianae Range is veneered by andesite. Lava flows of the Honolulu Volcanic Series, which mostly ponded in deep valleys and canyons, are, in general, dense and of low permeability.

Deep initial submergence of Oahu and somewhat smaller shifts in sea level have caused thick deposits of lagoonal sediments to accumulate behind developing barrier reefs to form wide coastal-plain areas.

A geologic map of the island, prepared by Macdonald and Abbott (1970), is shown in figure 72. The stratigraphic sequence and water-bearing properties of the rocks (after Stearns 1939) of the Koolau and Waianae Ranges are shown in the following tables.

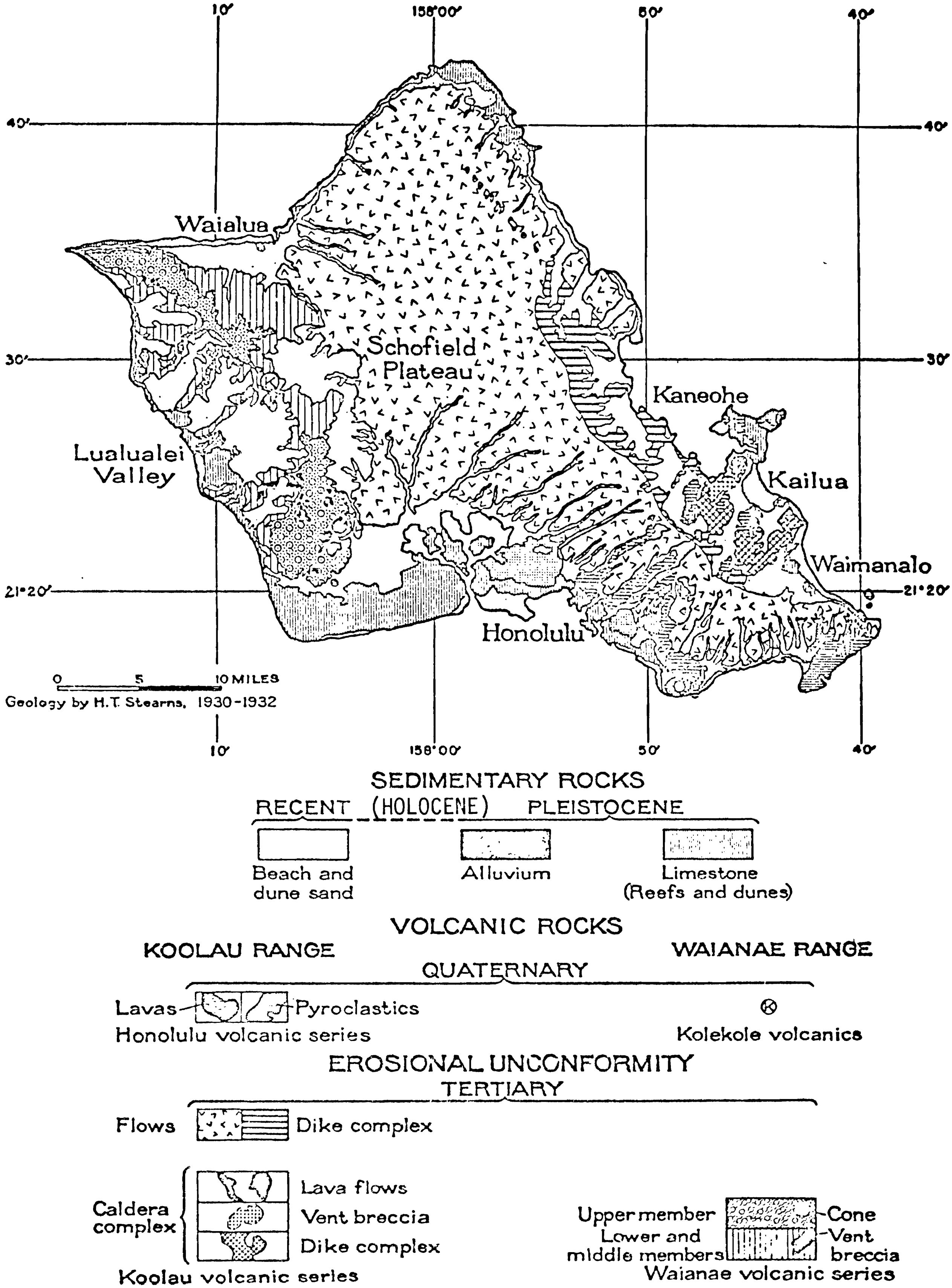


Figure 72. Geologic map of the island of Oahu. (Modified after Stearns, 1946.)

Table 16. Stratigraphic units, Koolau Range

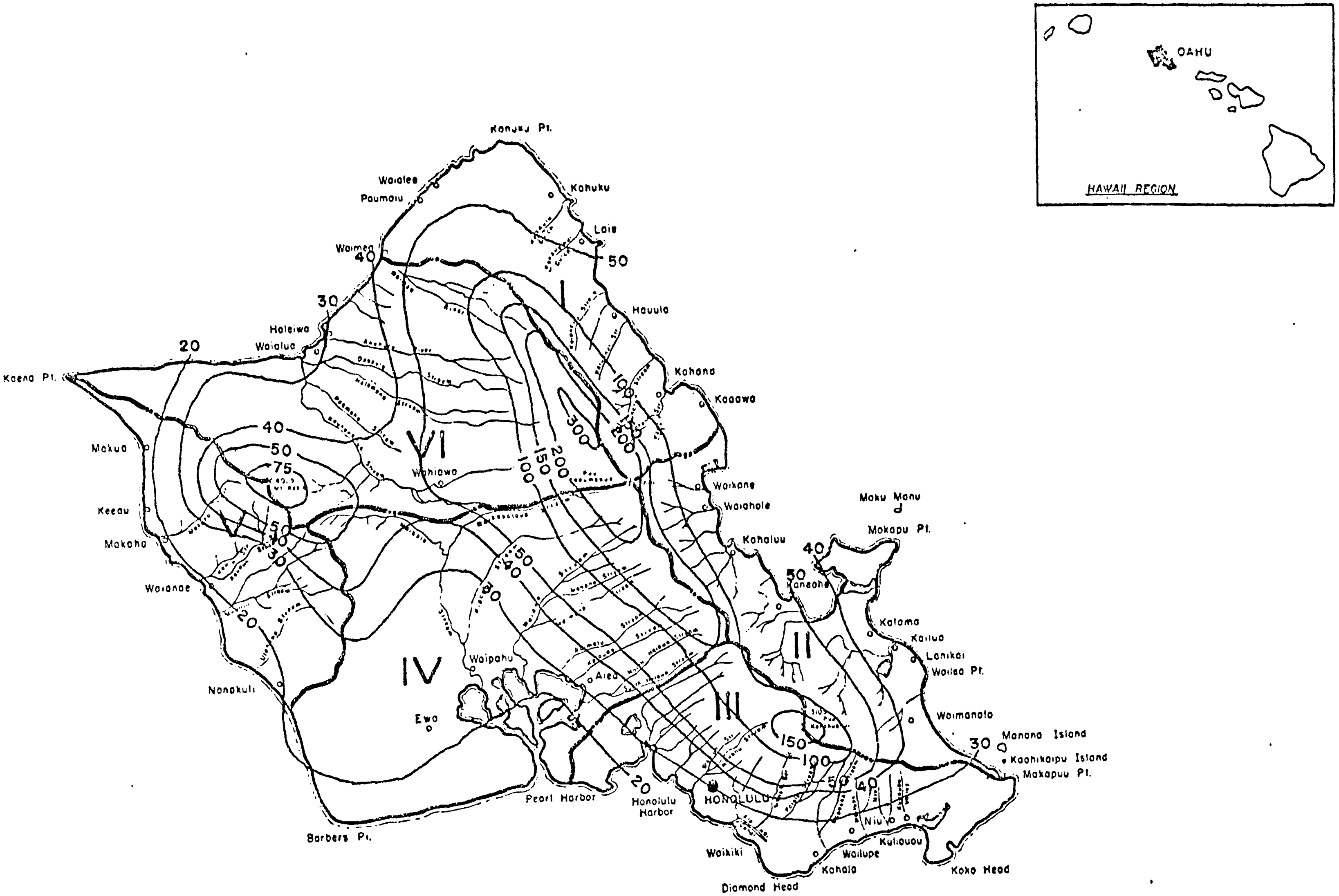
Age	Geologic unit	Rock assemblage	Water-bearing properties
(Holocene) Recent and Pleistocene	Calcareous sedimentary material	Coral and coral rubble, dunes, and recent beach sand.	Generally highly permeable except for consolidated sand dunes. Water likely to be brackish near coast where pumping is heavy.
	Alluvium	Older and younger alluvium. Older alluvium moderately to well consolidated and weathered in its entirety; mainly silt and clay and lesser amounts of sand, gravel, and cobbles. Younger alluvium reworked older alluvium in and near stream channels; mainly poorly consolidated fragments of older alluvium.	Generally poorly permeable; small quantities of water from shallow wells. Brackish near coast.
	Honolulu Volcanic Series	Lava flows, cinders, and tuff.	Lava flows moderately to poorly permeable; cinders are moderately to highly permeable and locally contain small perched bodies of fresh water; tuff is permeable where fresh but mostly poorly permeable because of alteration of volcanic glass to clay.
		—Major erosional unconformity—	
Pliocene(?)	Koolau and Kailua Volcanic Series	Lava flows, dikes, and breccia. Rocks free of dikes only in small area in northern part. Elsewhere rocks are intruded by numerous closely spaced dikes in dike complex and by scattered dikes in marginal dike zone. Kailua flows restricted to dike complex in and near Maunawili Valley. Breccia in minor quantities generally restricted to dike complex.	Lava flows highly permeable where free of dikes, moderately permeable in marginal dike zone, and generally poorly permeable in dike complex. Permeability also decreases with degree of weathering and secondary mineralization. Chief aquifer of high-level and basal water sources.

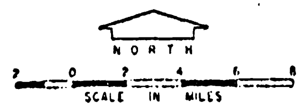
TABLE 17. STRATIGRAPHIC UNITS, WAIANAE RANGE

PERIOD	GEOLOGIC UNIT	ROCK ASSEMBLAGE	WATER-BEARING PROPERTIES
QUATERNARY	Calcareous sedimentary material	Coral, coral rubble, and beach sand.	Generally highly permeable. Water from wells likely to be brackish when wells are pumped heavily.
	Noncalcareous sedimentary material	Older alluvium: Moderately to well-consolidated and weathered in its entirety. Younger alluvium: Reworked older alluvium in and near stream channels and overlying older alluvium. Mainly reworked fragments of older alluvium. Talus: Mainly poorly consolidated gravel and boulders.	Older alluvium: Generally poorly permeable; acts as confining member where it overlies more permeable saturated rocks. Younger alluvium: Poorly to moderately permeable; yield from wells is small, but quality is generally fair to good even near coast. Talus: Highly permeable, but storage is generally small.
TERTIARY	Waianae Volcanic Series	Upper member: About 2,300 feet thick, mostly massive aa andesite flows that issued from large cinder cones. Flows sparsely intruded by dikes. Middle member: Exposed part about 2,000 feet thick; resembles lower member but more aa than in lower member. Mostly dike-intruded in Waianae District. Separated from lower member in most places by angular unconformity and breccia and in few places by erosional unconformity. Includes 400-foot thick trachyte flow at Mount Kuwale between Waianae and Lualualei Valleys. Lower member: Exposed part nearly 2,000 feet thick, mostly thin-bedded pahoehoe. Mostly dike-intruded in Waianae District.	Upper member: Generally poorly permeable owing to massive nature of flows. Acts as perching member of marsh on Kaala. Cinders generally permeable but drain quickly after heavy rains. Middle member: Permeability highly variable, depending on number and nature of dike intrusions. In Waianae District nearly all flows of the middle member are dike-intruded. Breccia generally poorly permeable and is probably barrier to movement of ground water. Trachyte flows are poorly permeable. Lower member: Permeability highly variable, depending on number and nature of dike intrusions. Permeability decreases with increasing number of dike intrusions. In Waianae District nearly all flows of lower member are dike-intruded.

Rainfall

The average rainfall on Oahu is about 65 inches per year, which is equivalent to 1,800 mgd. Most of the rain falls on the Koolau Range. Rainfall is highest in the northern part of the Koolau Range, where it is more than 300 inches per year. The highest rainfall on the Waianae Range occurs at Kaala, where the annual rainfall is slightly more than 100 inches. Leeward areas, lying in the shadow of the Koolau and Waianae Ranges, receive much of their precipitation from Kona storms. A rainfall map of the island is shown in figure 73.





SUBREGION 6
ISLAND OF OAHU

FIGURE 73. AREAL DISTRIBUTION OF RAINFALL.

Surface Water

Perennial streams on the island occur in windward Oahu from Maunawili to Kaluanui where low flows are sustained by leakage from high-level dike compartments and from springs and seeps. In certain sections of the leeward slopes of the Koolau Range, some streams are perennial in their headwaters, fed by persistent rainfall. But, except in the area between Palolo and Kalihi, flow to the sea is intermittent because of diversions for sugarcane irrigation or because the water sinks into the ground after the streams leave the mountains.

Outflow of basal ground water as springs in Pearl Harbor maintains perennial flows near the shoreline.

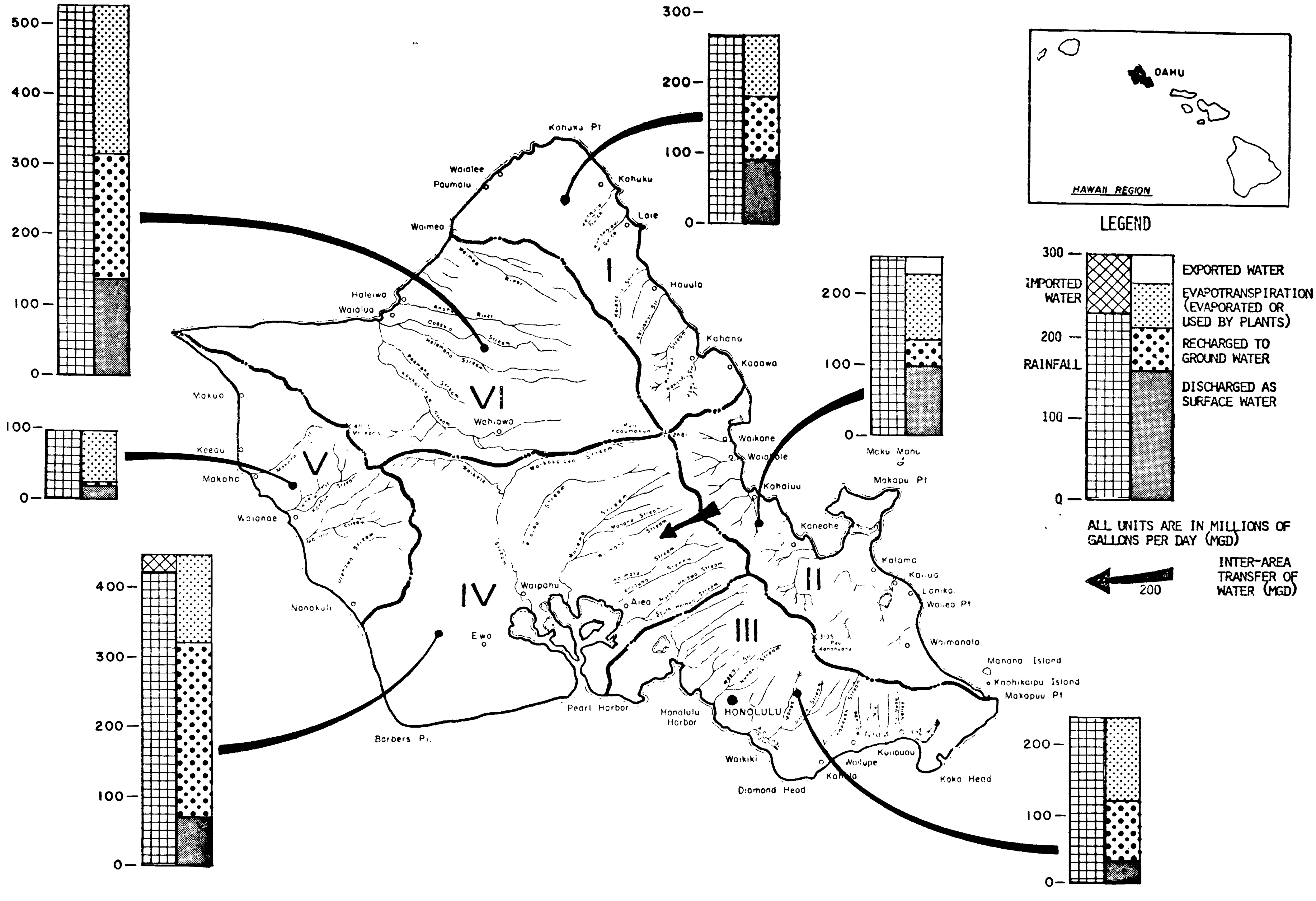
Runoff into the ocean is estimated at about 20 percent of rainfall or 350 mgd.

Ground Water

Ground water occurs as basal water, as dike-impounded water, and as perched water. The principal aquifer is the lava flows of the Koolau Volcanic Series, which provides 340 mgd of the total 410 mgd of ground water developed. About 140 mgd of the ground water developed supplies domestic needs of civilians and the military, about 170 mgd supplies irrigation water for sugarcane, and the remainder, for other miscellaneous uses.

The occurrence of water and the geologic features that control its movement and availability are described by areas.

A rough accounting of the disposition of rainfall on the island of Oahu is shown in figure 74 and in table 18.



SUBREGION 6
ISLAND OF OAHU

FIGURE 74. WATER OCCURRENCE, OAHU.

Table 18. Disposition of Rainfall

Island of Oahu
(Units in mgd)

Area	Rainfall	Evapotranspiration	Runoff	Ground-water flux
I	270	90	85	95
II	255	115	100	40
III	235	120	30	85
IV	425	130[a/]	70	250
V	98	77	15	6
VI	520	210	130	180

a/ Includes 25 mgd imported from Area II.

Quality of Water

Surface-Water Quality

Because of its high population density and its multiple land-use practices, Oahu has the most varied water-quality pattern of all the islands. Stream water is generally excellent near the headwaters, but can accumulate significant amounts of dissolved solids, turbidity, bacteria, and nutrients before reaching the ocean. Irrigation practices, urban and man-related activities, contribute to Oahu's changing water-quality picture.

Chemical Quality

The chemical quality of surface water is characterized by the change in dissolved-solids content, which is low at the headwaters, but increases significantly downstream to the tidal reaches. At Kalihi Stream, for example, water just below forested lands has an average dissolved-solids content of 70 mg/l. The average content increases to 129 mg/l below residential and urban areas. At Opaeula Stream, there is nearly a tenfold increase in dissolved solids, from 26 mg/l at altitude 1,120 feet to 250 mg/l at the lower reaches near Haleiwa. A large part of this increase is probably due to agricultural and irrigation practices.

Dissolved Solids

Most perennial stream waters contain less than 200 mg/l of dissolved solids. Average concentrations for windward and Honolulu streams range from 78 mg/l to 117 mg/l. Concentrations are higher for streams flowing into Pearl Harbor and Waiaka Bay, oftentimes exceeding 200 mg/l during low flow. The averages and ranges of dissolved-solids concentrations for selected streams are shown in figure

Hardness

Oahu's surface waters are soft. Average hardness concentration is 51 mg/l. Streams in central Oahu have less than 20-mg/l hardness above 1,000-foot altitude. Hardness increases as the streams receive ground water or irrigation return water at lower elevations. In their lower reaches, Waikele, Waiawa, Waimalu, and Kalauao Streams all have hardness concentration values exceeding 60 mg/l during base or low-flow periods. For windward and Honolulu streams, hardness ranges between 20 mg/l and 60 mg/l.

Nutrient Content

Nutrient content for most surface waters is low. Streams that receive sewage effluent, industrial waste, and urban runoff contain measurable amounts of nitrogen and phosphorus. Research projects of the University of Hawaii indicate nutrient levels exceeding Hawaii's Water-Quality Standards at the lower reaches of Kalihi, Kapalama, Manoa, and Kaneohe Streams. Nutrient levels are generally higher during wet-weather conditions. Waikele Stream, which receives treated sewage effluent and irrigation water, has an average of 2.2 mg/l total nitrogen, and 1.2 mg/l total phosphorus for monthly samples analyzed in 1973.

Silica

Silica concentrations range from 2.0 mg/l to 66 mg/l in surface waters. Concentrations greater than 20 mg/l may be attributed to ground-water discharge; silica content of ground waters is relatively high. Silica is not physiologically significant to humans, livestock, nor fish, nor is it of importance in irrigation water, but it is particularly undesirable in boiler feed water. Silica forms scale deposits on steam-turbine blades and hot-water heaters.

Streams draining central Oahu, and the Honolulu area generally have silica-concentration range from 5 mg/l to 20 mg/l. In the windward streams, the range is 15 mg/l to 30 mg/l. Streams near the Pearl Harbor and Makaha areas have concentrations greater than 30 mg/l. Silica ranges could be indicators of dike or basal ground waters discharging into the streams.

Physical Quality

Turbidity and sediment loading of streams are major concerns for Oahu's coastal-receiving waters. During periods of heavy precipitation, most streams are turbid. Suspended-sediment concentration often exceeds 1,000 mg/l and concentrations greater than 10,000 mg/l have been recorded during storm runoffs from urban developments and agricultural lands. The color content of Oahu's streams is usually not very high.

Stream temperatures fluctuate with ambient conditions. Many of Oahu's streams have concrete-lined sections, which generally have a warming effect on the water. Highest temperatures are recorded at these channels during base-flow periods, and in the summer months.

pH in water is an expression of acidity or basicity. Oahu streams are slightly acid because of the influence of rainwater and organic soils. The average pH of most streams is 6.9 units. The highest recorded pH of 10.2 units for Palolo Stream was attributed to urban wastes seeping into the stream channel.

Biological Quality

Total coliform counts for all Oahu streams draining industrial and urban areas show densities greater than 1,000 colonies per millilitre of water, with some even greater than 10,000 colonies per ml. These magnitudes usually suggest polluted or unsafe water conditions. However, total coliform counts are generally high in tropical environments, and is not a positive pollution indicator. Fecal-coliform and fecal-streptococcus data are considered better indicators, but these are not currently available.

Limnological surveys on 21 streams have been completed by the State Division of Fish and Game. Twelve of the streams were judged to have excellent potentials for development into public fishing areas. Five streams were judged to have low potential, and four streams to have no potential because their flow is ephemeral.

Ground-Water Quality

The quality of ground water on Oahu is generally dependent upon the nature of its sources--noncalcareous sedimentary deposits, calcareous sedimentary deposits, or volcanic rocks.

Water in noncalcareous terrestrial sediments is quite fresh with chloride content of the water seldom exceeding 500 mg/l. Wells tapping this type of aquifer usually have small yields, and have been used mostly by truck farmers for crop irrigation in the Waianae area. The range in chloride content of well water from noncalcareous sedimentary deposits as compiled by Lindsay Swain (1973) is shown on figure

Water in the calcareous sedimentary deposits is of poor quality and is generally too saline for domestic use. The dissolved-solids content is high, predominantly of sodium chloride. The aquifer is extensively intruded by seawater, but it is still a major source of water for sugarcane irrigation in Ewa. It is also an important water source for cooling air-conditioning units in Honolulu. The recent practice of using the calcareous sedimentary aquifer as receptacles for subsurface waste disposal could contaminate the aquifer, and further limit the use of the water. The range in chloride content of water from wells tapping calcareous materials as compiled by Swain (1973) is shown on figure

Most of Oahu's ground-water supplies for public use is developed from volcanic rocks. The water occurs as high-level water, dike water, and as basal water. All the water is chemically suitable for use without treatment. The dissolved-solids content is within drinking-water limits recommended by the U.S. Public Health Service. No significant levels of toxic chemicals, heavy metals, pesticides, or other organic contaminants have been reported for Oahu's potable water sources. The water is relatively free of bacteria, turbidity, and color.

Dike-Impounded Water

Dike water occurs in the Koolau Range, Waianae Range, and the central-plateau area. The chemical constituents of the water appear to have been derived almost entirely from rainfall interacting with the soil and rocks within the area. The water has low mineral content; dissolved-solids concentration is generally less than 200 mg/l, and the principal dissolved minerals are sodium, calcium, magnesium, and bicarbonate. The water is soft; average hardness concentration is less than 60 mg/l. Silica content of water in the central-plateau area is higher than those of other high-level water; concentrations range from 40 mg/l to 80 mg/l in the plateau area as compared to the range from 20 to 40 mg/l in other areas.

Water in the northwestern edge of Waianae Range and in the northern coast of the Koolau Range is somewhat affected by seawater intrusion. Water in both these areas has high dissolved-solids content. The chemical character of this water is more like that of basal water than dike water.

An anomaly is noted for water from a well in the central Waianae Range near Kolekole Pass. This water has a significantly higher dissolved-solids content than those of surrounding sources. It has a relatively high temperature of 26.7^{o}C, and contains high concentrations of sodium and sulfate. This anomaly may be due to a possible geothermal hot spot in the area.

Basal Water

Basal-water sources developed for public supplies occur generally in the northwestern, northern, and the southern areas on Oahu.

The quality of basal water in the northwestern area varies from good to marginal. Dissolved-solids contents range from 280 mg/l to 590 mg/l in areas with high artesian head (10-24 feet above mean sea level (msl)). The dissolved-solids content exceeds 900 mg/l in other areas where the water table is less than 5 feet above msl. The Sunset Beach well, located in a lowhead area, is noticeably draft-sensitive. The dissolved-solids content of the well water averages 430 mg/l.

Basal water in the northeastern edge of the Koolau Range has been developed to service communities from Kaaawa to Laie. The quality of this water is excellent. The water is predominantly of the sodium-magnesium-chloride type, and the dissolved-solids concentrations generally are less than 250 mg/l.

Basal-water development is most extensive in the southern Oahu areas near Pearl Harbor and Honolulu. In general, the quality of water in the Honolulu area is excellent and also slightly better than in the Pearl Harbor area. Dissolved-solids concentration is less in Honolulu where the aquifer is not readily affected by irrigation practices. Analyses of basal water near Honolulu generally show the following:

Parameter	Concentration range
Dissolved solids	200 - 300 mg/l
Silica	30 - 40 mg/l
Hardness	Less than 100 mg/l
Alkalinity	50 - 90 mg/l
Specific conductivity	200 - 400 μmhos

Exceptions exist in waters from the Waialae Shaft and from the Aina Koa well. These waters contain greater concentrations of dissolved minerals, a situation which may be attributed to slower water movement in these areas.

Basal water in the Pearl Harbor area has varying chemical characteristics. Chloride is the major anion, but there is no one predominant cation in the water. Calcium and magnesium contents are high due to cation exchanges. Sodium predominates where seawater intrudes into the aquifer.

Nitrate in Water

Under natural conditions, the nitrate content of water is low. It averages less than 1.1 mg/l in rainfall, in native fresh water, and even in seawater (Mink 1961). Nitrate contents higher than 1.1 mg/l may be considered to be an indication of contamination from return irrigation water. Although sewage effluent has high nitrate content, its effect on ground-water bodies is generally local. The major source of widespread and significant nitrate levels on Oahu appears to be irrigation return water; areas of greatest nitrate concentration correlate with known areas of irrigation. The nitrate content of water in these areas ranges from 8 to 10 mg/l. Where irrigation has ceased, as in the Pearl City area, the nitrate content, as well as other ions in water, has decreased significantly.

Physical and Bacteriological Quality

Ground water on Oahu is of excellent physical quality. The water is usually free of turbidity, color, and odor. It is slightly basic; pH values range from 7.0 to 8.3 units except in the Schofield area.

The bacteriological quality of ground water is excellent. Incidence of coliform contamination is low, and chlorination is seldom needed for most public water supplies. Surface-water and spring sources have shown some incidences of coliform contamination. Incidences of coliform (average for 5 years) for all public water sources, as compiled by Honolulu Board of Water Supply, are shown in figure 75.

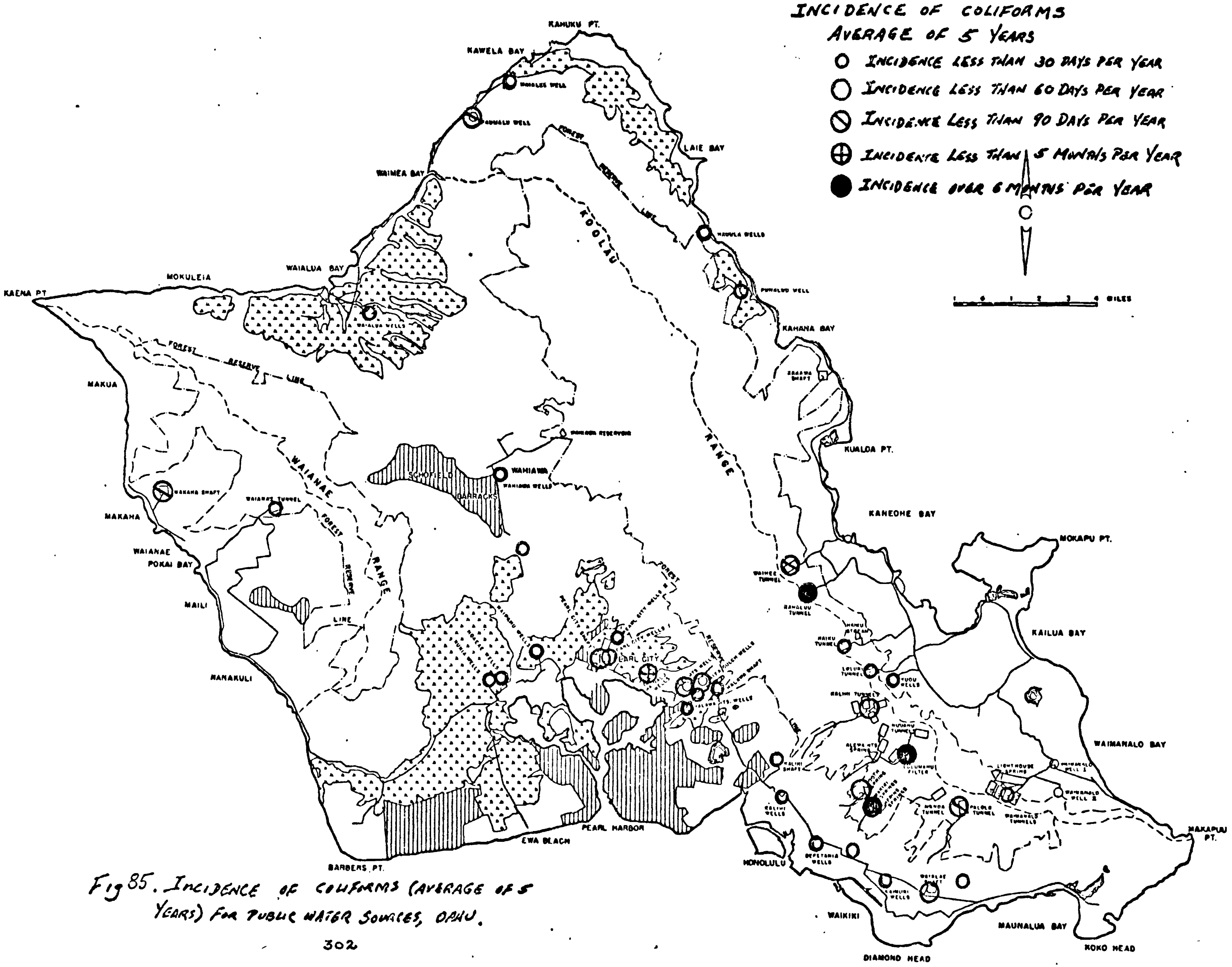


Fig 85. Incidence of coliforms (average of 5 years) for public water sources, Oahu.

Area I

Geology

This area hooks around the northern end of the Koolau volcano and includes over 17 miles of coastline (see fig. 72). Approximately 2 square miles of the crest area between Hauula and Punaluu is underlain by dike complex. The marginal dike zone, which continues out to sea as a broad band between Kahuku Point and Kalou Marsh, comprises slightly less than half of the area. Dike-free rock occurs east and west of the marginal dike zone. A fairly well-developed coastal plain extends from Punaluu to Waialee. From Punaluu to Kaaawa, bedrock spurs of Kahana Valley interrupt the continuity of the coastal apron.

Rainfall

The crest area between Punaluu and Hauula receives an average annual rainfall of 300 inches in contrast to the 40 inches at the coast. Most is trade-wind rainfall, which is heaviest near the crest and which decreases rapidly downslope. It occurs throughout the year, but is most frequent in summer, when trade winds are strongest. Occasional Kona rainfall is generally more uniformly distributed areally.

Surface Water

Kahana, Punaluu, and Kaluanui Streams flow in valleys that cut deeply into dike structures and flow perennially into the ocean. Other streams in the area may have flows that are perennial in the upper reaches but do not reach the ocean except occasionally.

Measured flows in northern streams average:

	Mgd
Kahana	29.5
Punaluu	24.2
Kaluanui	2.8
Koloa	2.7
Wailele	1.6
Kahawainui	.8
Malaekahana	2.9
Kamananui	10.1
Total	74.6

Ground Water

The principal occurrence of ground water relative to developable supplies is basal water. Basal water occurs on either side of the dike zone which straddles the crest of the Koolau Range. The zone is roughly 2-1/2 miles wide and 12 miles long. Between the coastal plain and the marginal dike zone, the dike-free basal water is unconfined. Beneath the coastal plain from Punaluu to Waialee, the aquifer is confined. Fresh-water flow is seaward and toward Kahuku from Punaluu. Change of land use from sugar plantation to suburban has resulted in both a shift in pattern and quantity of pumpage. Well fields for domestic water have replaced plantation wells in the Punaluu-Kaluanui area. Plantation pumps revived for irrigation of diversified crops, chiefly between Malaekahana and Kahuku, account for only a portion of the former local ground-water withdrawal. The area between Kalou Marsh and Waimea River contains low-head basal water, owing to the lack of adequate caprock. Thinness of the fresh-water body and sensitivity to pumping restrict widespread development of the source.

Within the marginal dike and dike-complex zones, development of water is more difficult owing to reduced content of water-yielding rock and the restraint to lateral flow by dikes. Furthermore, development of this water will cause a reduction of streamflow and the underflow passing to the basal-water areas. Because water moves parallel to the trend of the dikes, ground water moves to the stream valley, which act as drains with Kahana Valley being the largest.

Water quality of high-level, dike-impounded water and associated surface water is uniformly excellent and is characterized by a low concentration of dissolved minerals. The high-level water sources will not be affected by salt-water intrusion, but the sources located within dikes of the rift zone at the northern terminus of the range are subject to degradation by underlying salt water. Despite known large water fluxes through the basal-water areas and substantial prevailing fresh-water heads, wells are subject to upconing of salt water induced by excessive pumping rates. Since lower-quality water is no longer used for irrigation of upland infiltration areas, the degradation of the upper portion of the fresh-water lens is expected to dissipate with time in the Kahuku area. The presence of the irrigation return water is easily identified by anomalously high nitrate, increased chloride, and dissolved-solids concentrations as compared for typical basal water.

An approximate water budget is summarized below:

	Mgd
Input	
Rainfall	270
Output	
Runoff	85
Evapotranspiration	90
Ground-water flow	95

Present Use of Water

Surface Water

At present, all streamflow except for a small diversion in Punaluu Valley for supplying a few homes, wastes to the sea.

Ground Water

These small private systems and three municipal installations pump a total of approximately 8 mgd.

Potentials for Development

Surface Water

A substantial quantity of surface water wastes to sea but the developable long-term dependable amount with due regard to existing water rights is only a fraction of the average flow. Kahana Valley and Punaluu Valley contain developable water that will require treatment before it can be used for domestic purposes. Ground-water projects in the dike areas of these valleys will reduce streamflow.

Ground Water

The best potential for additional ground water is in the mid and upper reaches of the major streams to prevent effluent loss as streamflow. If the diversified agriculture replacing former cane land does not utilize the same quantities of water, then new wells can be located in these areas to develop better quality water.

Area II

This area, about 72 square miles, extends approximately 20 miles from Makapuu Point to the interstream divide between Hakipuu and Kaaawa Valleys, and extends from the Koolau crest to the sea. (See fig. 72)

Geology

Dike complex comprises nearly two-thirds of the area, whereas the remaining area of marginal dike zone occurs along the crest, with a small portion lying seaward of the Waikane reach. The caldera occupies an area of 4 miles by 5 miles in the Kailua area lying between Waimanalo and Kaneohe. Honolulu Series vents are responsible for a number of isolated flows or phyroclastics from Haiku to Makapuu. Profound erosion stripped away and exposed the caldera area and backbone of the range. Caprock occurrence is widespread but discontinuous because of intervening bedrock spurs.

Rainfall

The precipitous face of the range induces an elevation-related orographic rainfall ranging from a low of 30 inches near Makapuu to 250 inches at the Kahana crest. Deep infiltration recharges compartments of the marginal dike zone from whence the flow of ground water is either parallel to the main trend of the dikes or across the dikes as overflow or leakage. The numerous perennial streams of this area derive base flow from breaching of the saturated zone of dike compartments. Rain upon the dike complex and the caldera area is largely lost to runoff, owing to a perennially saturated condition caused by low permeability. In general, the caprock areas receive lower rainfall.

Surface Water

Streams heading in deep valleys are fed by drainage from dike-controlled water bodies and are generally perennial. Inflow from ground water between altitudes of about 150 to 200 feet also adds to stream discharge in valleys between Maunawili to Hakipuu.

The following table (Hirashima 1969) summarizes streamflows in windward Oahu.

Table 19. Inventory of streamflow for all perennial streams in windward Oahu

Stream	Average discharge (mgd)
Waimanalo	0.7
Maunawili	7.8
Kahanaiki	1.0
Kawa at altitude 70 ft	1.0
Kamooalii	8.5
Kaneohe tributary at altitude 60 ft	2.8
Keaahala	3.4
Haiku	2.4
Iolekaa	1.0
Heeia at altitude 90 ft	2.1
Ahuimanu	4.1
Kahaluu at altitude 358 ft	3.5
Kahaluu	1.9
Waihee	6.5
Waihee at altitude 160 ft	2.7
Kaalaea at altitude 90 ft	2.4
Waiahole ditch tunnel, north portal station	26.1
Waiahole ditch tunnel, main bore	2.6
Waiahole	6.9
Waianu	1.2
Waikane at altitude 75 ft	4.2
Hakipuu	1.1
Kaaawa	1.0
Total	94.9

Ground Water

Most ground water occurs in lava flows of the Koolau Volcanic Series, and lava flows make up the bulk of the Range. Dikes generally retard and control ground-water movement, but near the coast at the northern end of the area, dikes are few and alined in such a way that some basal water occurs. In the southeastern part of the area, water is perched in small scattered bodies in rocks of the Honolulu Volcanic Series. Basal water occurs in calcareous sedimentary rocks at the southern end. It may also occur in the marginal dike zone adjacent to the ocean.

Development of water sources in this area has been almost exclusively in the marginal dike zone below the crest by means of tunnels driven into successive dike compartments and to a minor extent by drilled wells.

A large quantity occurs as storage, but a substantial portion is lost during tunnel construction. If flow-regulating bulkheads can be constructed at the breached dikes, restoration of storage is possible, as has been demonstrated at Waihee Tunnel. Elevation of water surfaces in the dike compartments along the crest range from about 400 feet at Waimanalo to over 700 feet at Kahana, but in all areas, the water surfaces decline in elevation toward the coast.

Below an elevation of about 200 feet, the increased frequency of dikes and weathering of the rock inhibit easy development of ground water. The poorly permeable caldera rocks are unimportant, source wise. A few areas of alluvium may be locally important as potential, small to moderate, supplemental sources.

As a whole, the location, disposition, and small extent of the Honolulu Series make them unimportant hydrologically, as water sources. The exception is the Haiku volcanics, which perch locally appreciable water presently used only for a fish pond. A small amount of water is perched on Honolulu Series in the area between Hale Kou and Castle High School but no developmental effort has been made yet.

Further development of the marginal dike-zone source will reduce the quantity of surface water currently wasting to sea by reduction of the base flow. The low areas are unlikely to be developed because of their urbanized status and unfavorable benefit cost ratios.

Water from tunnels and wells in the dike compartments is of excellent quality and characteristically contains a very low concentration of dissolved minerals. Except for shallow wells at the coastline, salt-water intrusion is not a problem.

Approximately 5 mgd is pumped from wells. Tunnel developments supply about 12 mgd for domestic use. An extensive tunnel development develops 25 mgd for transport to the Pearl Harbor area for irrigation of sugarcane.

Present Use of Water

Surface Water

An average of 0.27 mgd is intercepted by the Maunawili Ditch for transport to Waimanalo farms. Approximately 0.5 mgd is diverted from Waihee Stream for taro irrigation with the unused remainder returning to the stream.

Waiahole Tunnel intercepts underflow that formerly discharged as springs sustaining streams from Waiahole Valley to Kahana Valley. In excess of 1 mgd is lifted by pump from Waiahole Stream into the tunnel for transport to the leeward area. Surface water is diverted into the tunnel at many points but principally from Kahana Valley (3.1 mgd) and Waiahole Valley (2.7 mgd, includes pumped water from the stream).

Ground Water

Ground water is extensively developed for domestic consumption. Except for a low-yield well at Waimanalo and two wells of 1 mgd each at Waihee and a 3-mgd well at Kuou, all of the water comes from tunnels driven into dike compartments. The Board of Water Supply produces an average of 12 mgd from 8 tunnels.

Waiahole Water Co. develops an average of 25 mgd from a transmission and development-tunnel system stretching from Waiahole Valley to Kahana Valley. This water is transported to leeward central Oahu for irrigation of sugarcane.

Potentials for Development

Surface Water

The table of streamflow inventory of perennial streams in windward Oahu indicates the average flow in these streams. Base flow is considerably smaller but is the dependable amount that could be developed without construction of large reservoirs, which are not feasible in this area. Development for homes in some of the drainage areas removes them from present consideration for development. The streams with the most potential for development are Maunawili, Kamooalii, Waihee, Waiahole, and Kahana. At present, only Kahana with a dependable flow of 10 mgd is considered for possible future development of ground water. Plans to retain an ever-flowing stream in the State Park along with a decrease of flow, due to development of ground water, would leave only a portion of the streamflow, which could be developed.

Ground Water

Assessing the total potential is difficult without having a complete inventory of base flows of the streams at strategic locations because of the interrelationship of stream and ground-water discharge. Development of dike-complex water is not economically feasible although the water is there. Difficulty of terrain, remoteness from transmission, and distribution systems also impose restrictions on development of water in the marginal dike zone.

An approximate water budget is summarized as follows:

Source	Recharge (mgd)	Discharge (mgd)
Rainfall ----------------------------------	255	
Overland storm runoff to sea --------------		100
Ground-water draft ------------------------		40
35 mgd from tunnels (25 mgd exported)		
5 mgd from wells		
Evapotranspiration ------------------------		115

Area III

Area III stretches from the Moanalua-Halawa interstream divide to Makapuu Point and from the Koolau crest to the shoreline, encompassing approximately 85 square miles. This is the most complex area on Oahu from a hydrogeologic standpoint.

Geology

The area is underlain by basaltic rock lying southwest of the crest of the Koolau Range. The coastal portion of Area III lies on a broad coastal plain and deeply alluviated valleys. Thin-bedded lava flows of the Koolau Volcanic Series comprise the bedrock. Lava flows and pyroclastics of the younger Honolulu Volcanic Series overlie and are interbedded with alluvium in valleys and also cover isolated small portions of the Koolau slopes in the Area III. The coastal plain is underlain largely by terrestrial and marine sedimentary deposits.

The principal aquifer consists of the highly permeable Koolau lava flows. Where dikes intrude these rocks, the dikes impound water. Lavas and pyroclastics of the Honolulu Volcanic Series are limited in extent and volume and contain only small amounts of water. The term "caprock" is used to include a section of interbedded sedimentary deposits of marine and terrestrial origin that act as a barrier to the seaward flow of ground water from the permeable volcanic aquifers.

Rainfall

The areal variation in annual rainfall is very great. It ranges from 20 inches at the southern coast to more than 200 inches near the crest of the Koolau Range in the northern part. The higher mountain rainfall is mostly the result of precipitation from trade-wind showers, and the lower rainfall near the coast is mostly the result of "Kona" storms and winter cyclonic rainfall.

Surface Water

Perennial flows occur in streams between Palolo and Kalihi. Other streams flow in their upper reaches during the winter months.

Measured flow in streams of this area average:

	Mgd
Kalihi Stream --------------	8.3
Nuuanu Stream --------------	4.7
Manoa Stream ---------------	5.7
Palolo Stream --------------	3.8
	22.5

Ground Water

The presence of a continuous coastal plain underlain by thick caprock in conjunction with high rainfall on upland recharge areas is responsible for the occurrence of thick fresh-water lenses from Moanalua to Kaimuki.

Although the coastal plain continues easterly and, thence, north to Makapuu Point, the caprock thins from Wailupe Valley eastward. Low rainfall in the watershed and leakiness of the caprock are responsible for low fresh-water heads and a very thin fresh-water lens. Near the Koolau crest, dike-impounded water occurs, but these sources have not been exploited because of remoteness and difficult terrain. Underflow from the dike areas moves to the basal-water areas. Brackish water occurs in coralline aquifers.

The Waialae area is bounded by the alluvial fill of Wailupe Valley and on the west by the Palolo Valley fill and to a lesser extent by the rift zone extending from Kaau Crater to Diamond Head. Lesser rainfall and thinner caprock result in moderately low heads and a thin but developable fresh-water body. Dikes impound high-level water near the crest; however, the impounding efficiency of the system of dikes transverse to trend of the Koolau Range has not been verified by drilling.

Present Use of Water

Surface Water

Little, if any, surface water is diverted for use.

Ground Water

Pumpage of ground water is about 55 mgd almost exclusively for domestic consumption with a small amount for industrial purposes. Caprock water pumped for air conditioning is normally put back into the ground.

The following ground-water bodies provide most of the water pumped:

	Mgd
a) Basal water, Koolau aquifer -----	55
b) Perched water, Area III ---------	1.5
Total ---------------------	56.5

A rough accounting of the disposition of rainfall is given below:

	Mgd
Input	
Rainfall ----------------------------------	270
Output	
Runoff -------------------------------------	85
Evapotranspiration ------------------------	90
Infiltration ------------------------------	95

Potentials for Development

Surface Water

The perennial flows of streams between Kalihi and Palolo are available. However, because the water is not bacteriologically safe, except when treated, the potential may be limited.

Ground Water

The best potential for development of additional ground water is from caprock sources which generally tend to be brackish. Deeper in the valley, water perched on and within the later valley-filling lava flows and alluvium can also furnish small amounts of water.

Area IV

This area, about 165 square miles, encompasses the drainage of the Waianae and Koolau Ranges flowing to the sea and Pearl Harbor from Nanakuli to the interstream divide between Halawa Stream and Moanalua Stream.

Geology

The area is underlain by rocks lying southwest of the crest of the Koolau Range, east of the crest of the Waianae Range, and south of the summit of the Schofield Plateau. Thin-bedded lava flows of the Koolau Volcanic Series make up the bulk of rocks. The western part, comprising the Waianae Range, is mostly covered by a massive veneer of andesitic lava flows of the Waianae Volcanic Series. The Pearl Harbor area contains a broad coastal plain underlain largely by terrestrial and marine sedimentary deposits.

The principal aquifer consists of the highly permeable Koolau lava flows. Where dikes intrude these rocks and rocks of the Waianae Series, the dikes impound water. The term "caprock" is used to include a section of sedimentary deposits and weathered volcanic rock that act as a barrier to the seaward flow of ground water from the permeable volcanic aquifers.

Rainfall

The areal variation in annual rainfall is very great. It ranges from 20 inches at the southern coast to more than 200 inches near the crest of the Koolau Range in the northern part. The higher mountain rainfall is mostly the result of precipitation from trade-wind showers.

Surface Water

There is no perennial flow off the Waianae slopes and off the extreme southeastern end of the Koolau Range. Other streams, Waikakalaua to Moanalua, flow in their upper reaches during the winter months. The streams flowing into Pearl Harbor generally have perennial flow in their extreme lower reaches because of inflow from basal-water seeps and springs. Return irrigation water also augments the flow in these streams.

Measured flow in streams in this area average:

	Mgd
Waikele Stream	25.6
Waiawa Stream	21.3
Kalauao Stream	2.0
Waimalu Stream	5.3
Halawa Stream	6.7
Moanalua Stream	2.1
Total	63.0

Ground Water

The presence of a continuous coastal plain underlain by thick caprock in conjunction with high rainfall on upland recharge areas is responsible for the occurrence of a thick fresh-water lens from Ewa to Moanalua. The hydrologic budget is presented in figure

Near the Koolau crest, dike-impounded water occurs, but these sources have not been exploited because of remoteness and difficult terrain. Underflow from the dike areas moves to the basal-water areas. Brackish water occurs in coralline aquifers.

The Pearl Harbor district is the largest on Oahu in terms of size and water resources. Pumpage and water use are greater than all the rest of the hydrologic areas combined. Input to the principal Pearl Harbor area includes underflow from the Schofield high-level water, Koolau dike-compartment discharge to basal areas, direct infiltration of rainfall on the watershed, irrigation return water from ground water and imported surface-water sources, and some potential underflow from the Honolulu district. Historically, discharge of Pearl Harbor ground water has been by means of the numerous and large springs around the inner perimeter of the harbor where the caprock is breached or absent. Discharge of the springs is head dependent and the quantity has decreased over the past 90 years to approximately half of the highest recorded flows.

Two other subareas within the district are located in the Waianae aquifer. The larger one is distinguished from the Koolau area by a ground-water barrier that is expressed by abrupt water-level differences. The weathered Waianae surface at depth is believed to retard free movement of ground water. The boundary runs north-south slightly west of the plantation town of Ewa. The limited resources of the area are essentially fully developed for agriculture and domestic use.

The remaining subarea is quite small and separated from the above ground-water area by a poorly known ground-water barrier across which water levels drop 10 feet on the west side. The boundary of this area is arbitrarily placed at the hydrologic divide separating Nanakuli and Kahe Valleys. Thinness of the lens and brackish water in a few test holes indicate development prospects here for domestic-quality water use are extremely poor.

The Schofield high-water area is discussed in the Waimea-Kaena-Wahiawa hydrologic area. Development of additional water in this area will affect basal water to the north and south by diminishing underflow.

As might be expected, water quality varies because of hydrogeologic complexity. The mountain or high water-level developments by tunnel, well, or spring capture are of excellent quality with low dissolved mineral content. Shallow tunnels and springs are treated with chlorine to meet standards for bacteria content. Wells in the Wahiawa area are slightly acid. The Wahiawa well water also contains an unexplained high-silica content.

Quality of the basal-water sources is generally excellent, but in certain locations, overly deep wells pump brackish water. Excessive pumping rates induce upconing of salt water and historically, the fresh-water lens has shrunk and the transition zone has expanded and moved up. These waters are essentially diluted seawater with a relative enrichment of calcium and magnesium at the expense of sodium and reduction of sulfate. Irrigation return water and enrichment of nitrate from fertilizers occur in the Pearl Harbor wells. Spring discharges into Pearl Harbor are similar; in general, the closer to the harbor, the more brackish the water.

Present Use of Water

Surface Water

With sugar plantings discontinued east of Waiawa Stream, the use of surface water for irrigation is limited to water brought into this area from windward Oahu through the Waiahole Ditch system, a small diversion from Kipapa Stream. Water from the lower reaches of Waikele Stream is, at times, also pumped to sugarcane fields.

About 0.1 mgd of surface water is being used for domestic purposes.

Ground Water

Pumpage of ground water is about 295 mgd. Of this amount, about 90 mgd is pumped for domestic use and about 185 mgd for irrigation, mostly of sugarcane.

The following ground-water bodies provide most of the water pumped:

	Mgd
a) Basal water, Koolau aquifer (includes spring discharge)---	245
b) Basal water, Waianae aquifer --	18
c) Caprock water, Ewa Plain ------	23
d) High-level water, Schofield Plateau ---------------------	9

Potentials for Development

Surface Water

The combined discharge of the springs, irrigation return of watercress fields, and the discharge of a water tunnel into Pearl Harbor are potential sources. However, because the water is not bacteriologically safe or slightly brackish, except when treated, the potential for development may be limited.

Ground Water

A rough accounting of the disposition of rainfall is given below:

	Mgd
Input	
Rainfall ------------------------	425
Import from windward area ------	25
Output	
Runoff -------------------------	70
Evapotranspiration -------------	130
Infiltration -------------------	250

The best potential of developing additional ground water lies in the caprock sources.

Area V

This area includes all of the land area west of the crest of the Waianae Range to the seacoast, terminating on the north at Kaena Point, and encompassing Nanakuli Valley at its southernmost boundary. The total area covers 62 square miles (see fig. 72).

Geology

The Waianae Range is composed of three groups of lava flows erupted during Tertiary time. Dikes intrude most of the volcanic rocks. They are sparse in the poorly permeable, massive, thick-bedded flows of the upper member, and are numerous in the highly permeable, thin-bedded flows of the lower and middle members of the Waianae Volcanic Series.

Narrow strips of breccia crop out across the heads of Nanakuli, Lualualei, and Keaau Valleys. The breccia is poorly bedded, unsorted, well cemented, and practically impermeable. The breccia forms a barrier to ground water percolating seaward.

Noncalcareous and calcareous sedimentary materials fill the deeply eroded valleys. Calcareous material dominates the sedimentary section along the coast and at shallow depths.

Rainfall

The leeward coast of the Waianae District experiences the lowest rainfalls on Oahu. Less than 20 inches of rain per year is normally recorded in some places. In the valleys and on the intervening ridges, the annual average ranges between 20 and 30 inches.

Only deep in the mountains does an appreciable quantity of rain fall. In the vicinity of Kaala, about 100 inches per year is normal, the highest in the area. Much of this total results from orographic conditions, but the rain that falls in the dry regions is derived almost exclusively from winter storms.

The trade winds are less common and weaker in this part of the island than elsewhere. On many days, a sea breeze rather than trade-wind flow is dominant. Starting in the late afternoon, air from the sea moves inland, then drifts back to the sea late at night. The days tend to be several degrees warmer than in most other parts of the island.

Surface Water

Rainfall is low throughout the area and there is no perennial flow, except in Makaha and Waianae Valleys. Dike water feeds the upper reaches of streams in the Makaha and Waianae Valleys, but in their lower reaches, these streams flow only during extremely heavy rains.

At points of measurement, the average flow for Makaha Stream is 1.3 mgd and for Kepuni Stream is 0.7 mgd.

Ground Water

Most of the fresh ground-water supply in the area occurs in flows of the lower and middle members of the Waianae Volcanic Series. Flows of the upper member occur mostly above the water table and contain only a small perennial supply. Some fresh water occurs in sedimentary materials, but development of this supply is generally limited by the low permeability of alluvium, the restricted storage available in talus, or by seawater intrusion in coral or coral rubble.

Basal Water

Basal-water bodies occur in volcanic aquifer in coastal areas but most are brackish except where dikes are present, in which case, limited quantities of potable water are available.

The principal occurrence of basal water is in highly permeable coral and coral rubble. The coral aquifer extends inland, at least 3 miles in Lualualei Valley and about 1 mile in Waianae and Makaha Valleys. About 100 wells have been drilled into this aquifer, but most have been abandoned because of an increase in chloride content of the water with continued pumping.

Small quantities of fresh water are available in alluvium.

Dike-Impounded Water

The dike-impounded ground-water reservoir is large. The top of the reservoir ranges from an altitude of a few feet near the coast to more than 1,800 feet near the crest at Kaala. Water levels in wells tapping dike-impounded water show, by their step-like gradient, effects of local changes in permeability-caused variations in dike density, dike intersections, and to breccia.

Discharge from dike-impounded reservoirs contributes to the perennial flow of streams in the higher altitudes. Most of the flow disappears below an altitude of 1,000 feet. Artesian conditions prevail where wedges of poorly-permeable older alluvium and weathered rock overlie the aquifer, as near stream channels.

Perched Water

Many small perched-water bodies occur but all are small and most go dry during dry weather.

Present Use of Water

Surface Water

Because the flow of streams are small, no large development of surface water has occurred. At present, only a small amount of surface water is taken from the uppermost reaches of Waianae Valley.

Ground Water

The average quantity of ground water developed in the area amounts to 3.3 million gallons a day. Of this total, the Honolulu Board of Water Supply provides an average of 2.3 million gallons a day; other users produce an average of 0.7 million gallons per day; while the military develops an average of 0.3 million gallons daily for domestic use at Lualualei.

The Board meets its requirements from three installations, which include two high-level tunnel systems and a shaft.

The military in the area satisfies its requirements from two installations, which include a high-level tunnel and a single well field.

Other users meet their needs from three installations, which include two high-level tunnel systems and a single well field.

Potentials for Development

Surface Water

No significant further development of surface water is foreseen.

Ground Water

The area is assumed to be a closed basin; that is, all water is recharged and discharged within the basin, except for overland storm runoff to sea. An approximate water budget is summarized as follows:

Source	Mgd	Mgd
Input		
Rainfall --	98	
Output		
Overland storm runoff to sea ------------------		15
Ground-water draft ----------------------------		6
4 mgd from tunnels 1 mgd from wells tapping volcanic rocks 1 mgd from wells tapping coral and alluvium		
Evapotranspiration ----------------------------		77

Evapotranspiration is the largest element of ground-water discharge in the area and, therefore, the potential for development of ground water depends on decreasing evapotranspiration. Most water is evaporated and transpired in low-lying areas, where water levels are shallow and kiawe grows luxuriantly. Heavy pumping would not lower water levels sufficiently to deprive the kiawe of water, and evapotranspiration would remain about the same. The most promising areas for ground-water development are in the deeper valleys in the mountains, where water levels are shallow and where evapotranspiration is comparatively small but still significant. Any reduction in evapotranspiration in such areas, by lowering water levels, would result in additional available ground water.

Area VI

This area consists of 152 square miles and includes mountainous terrain, part of the Schofield Plateau, and a narrow coastal plain (see fig. 72).

Geology

This area comprises the portions of the Koolau and Waianae Ranges draining northward between Kaena Point and the Waimea River. Much of the Waianae Range in this area is capped by thick andesitic lava flows. The Koolau Range, in contrast, is not capped by andesite but is composed throughout of thin-bedded basaltic lava flows.

The Koolau rocks appear to be more permeable than those of the Waianae, including the rocks underlying the andesitic cap.

Alluvium and marine sediments are small in volume and in areal extent and are limited mostly to coastal areas. These materials overlie lava flows in the coastal plain from Kaena Point eastward to the Waimea River and confine much of the water in the underlying aquifer.

Rainfall

Rainfall gradients are steep. Orographic lifting of moisture-laden trade-wind air causes light lowland rains and moderate-to-heavy mountain rains throughout the summer and part of the winter. Infrequent Kona storms, mostly in the winter months, provide most of the rainfall in the coastal areas. The rainfall in the area amounts to a quantity equivalent to 520 mgd.

Surface Water

Streams draining Koolau Range are perennial in the upper reaches but, because of diversions, are dry most of the time in the lower reaches, except for Kiikii and Anahulu Streams, which are fed by inflow from basal-water seeps and springs.

Streams draining the Waianae Range are dry most of the time.

One of the only two large reservoirs in the State is located on Kaukonahua Stream below the confluence of the North and South Forks.

Ground Water

Ground water occurs impounded between dikes as high-level or basal water, as basal water in dike-free rocks, and as perched water. For similar modes of geologic control, Koolau aquifers yield more water of better quality than do the Waianae rocks.

Basal Water

Basal conditions occur in dike-free volcanic aquifers of the Koolau and Waianae Ranges and to a lesser extent in dike compartments in the Kaena region. Within the Koolau aquifer there are two subareas, the Kawailoa area and the Waialua area. The Kawailoa subarea is located between the Anahulu and Waimea Rivers. Thinness and discontinuity of caprock do not effectively restrain discharge of fresh water to the ocean, giving rise to a thin lens and generally poor-quality water.

The Waialua subarea to the west contains a moderately thick fresh-water lens and extends between the Anahulu River along the coast to a point about a mile west of Waialua Bay and south to the Schofield high-level water. The coastal reach is confined by caprock, which allows head to build up to 10 feet. Fresh water emerges as springs and in the streams draining into Waialua and Kaiaka Bay. Ground water for cane irrigation and mill use is extensively developed.

The Mokuleia subbasin extends a distance of nearly 4 miles west of the Waialua subarea. Here, the Waianae aquifer is confined by caprock. Heads stand as much as 20 feet above sea level. Across the western boundary, heads drop from 16 feet to 10 feet. The caprock prism is thicker than at Waialua. Past and present use of water is almost exclusively for irrigation of sugarcane.

The extent of the adjoining isopiestic area has not been determined because only one well has been drilled. Kaena Point probably contains little, if any, developable fresh water.

Water quality of the subareas varies with the thickness of fresh water, depth of well penetration, and pumping rates. The only water development in the Kawailoa subarea pumped brackish water from a battery of shallow wells for irrigation and was abandoned long ago. The distribution ditch intersected the water table and water continues to discharge to Ukoa Pond.

In general, the best quality water occurs in the Waialua subarea, particularly inland. Heavily pumped wells at the sugar mill and other locations have induced upconing and a landward encroachment of salt water. These wells contain 10 times the chloride of unaffected wells and are slightly brackish. Return irrigation water from deep infiltration of excellent quality irrigation water contributes small amounts of nitrate and other dissolved minerals.

The Mokuleia subbasin water generally contains higher concentrations of chloride, apparently as the result of deeper well penetration into a draft-sensitive lens. Most of the wells have been abandoned, and only a relatively few remain active. New wells should be drilled farther inland, where the caprock is thinner and the requirement less for well depth.

Dike-Impounded Water

Lava flows of the Koolau volcano overlap the eroded older lavas of the Waianae volcano. The weathered surface of the contact is believed to be a barrier to free movement of ground water. Dike complex and marginal dike zones are encountered in the crest areas of both volcanoes. The high-level water beneath the Schofield Plateau stands at an altitude of approximately 280 feet. The exact nature of the geologic control responsible for the high-level water and the mechanism of underflow to adjoining basal areas is not completely understood but may be caused by an offshoot of the Koolau rift zone. Geophysical data and water levels indicate abrupt transitions, thus support a dike-control hypothesis. Overflow and leakage from the dike complexes, the Schofield high-level water, and marginal dike zones eventually move into basal-water areas. Rough terrain and remoteness from areas of use have delayed exploitation of these areas.

The Schofield high-level water is of excellent quality and contains low concentrations of dissolved minerals. Two unusual features of this water are the unexplained high concentration of silica and a low pH.

Perched Water

Ground water in the northwest end of the Waianae Range is perched on weathered ash beds, which are fairly extensive above an altitude of 200 feet. The quantity of this water body by springs is small. The discharge has been estimated by Stearns and Vaksvik (1935) at 70,000 gallons per day. About 10,000 gallons per day is used. Chloride content of the water ranges from 100 to 160 mg/l.

Present Use of Water

Surface Water

About 55 mgd of water is diverted from streams on the west side of the Koolau Range and about 35 mgd is used for the irrigation of sugarcane through diversion-collection distribution systems. The Wahiawa Reservoir is the largest reservoir in the system and in the islands. It has a storage capacity of 2.5 billion gallons and is formed by impounded water of the 17-square-mile Kaukonahua drainage system and the flood flow of the upper Poamoho system. Helemano Reservoir receives the normal flow of Poamoho Stream and the flow of Helemano Stream above an altitude of 1,074 feet. Opaeula Reservoir receives Opaeula and Kawaiiki streamflow above altitudes of 1,100 and 1,160 feet, respectively. The Kamananui Reservoir receives water from Kawainui Stream above an altitude of 713 feet. The lower parts of Poamoho and Helemano Streams are not utilized.

Rainfall variations cause annual fluctuations in the amount of streamflow available from the seven major drainage systems of north-central Oahu. The 5-year average annual streamflow of these systems, measured above the diversions, is 83 mgd. Streamflow in a dry year (1962) was only 53 percent of the 5-year average.

The following tabulation compares streamflow and water diversions during that year with those during a 5-year period (1962-66).

	Streamflow	
	5-yr average annual (mgd)	1962 (mgd)
Streams		
Kaukonahua -----------------	39	24
Helemano and Poamoho -------	13	5
Opaeula and Kawaiiki -------	16	8
Kawainui -------------------	6	2
Kamananui ------------------	9	5
Total ----------------	83	44

	Water diverted to reservoirs	
	5-yr average annual (mgd)	1962 (mgd)
Reservoirs		
Wahiawa -------------------	39	23
Helemano ------------------	6	2
Opaeula -------------------	8	4
Kamananui -----------------	4	2
Total ----------------	57	31

Sixty-nine percent of the 83 mgd average annual measured streamflow was diverted to reservoirs, and an average of 36 mgd was eventually applied to approximately 3,000 acres of sugarcane. The remaining 21 mgd and the 26 mgd that was not diverted recharged the aquifer, evaporated, ran off to the sea during storm periods, or was transpired.

Ground Water

Ground water is pumped at a rate of about 48 mgd. Of this amount, 34 mgd is pumped from basal-water sources, and the remaining 14 mgd from the high-level source in and north of Wahiawa. About 10 mgd supplies domestic and military needs, and the remaining 4 mgd is for sugarcane irrigation.

Potentials for Development

Surface Water

The extensive surface-water diversion system, now in operation, probably utilizes most or all of the flows economically obtainable. No further large developments are foreseen.

Ground Water

A rough accounting of the disposition of rainfall is given below.

	Mgd	Percentage of input
Input		
Rainfall	520	100
Output		
Surface runoff	130	25
Evapotranspiration	210	40
Infiltration	180	35
Total output	520	100
Underflow per shoreline mile	12	

The best potential for developing ground water is from water bodies in the Mokuleia and the Waialua subareas at locations inland as far as feasible from the coast. The developable quantities will depend on susceptibility of the wells to intrusion and upconing of salt water and also the influence of these wells on existing coastal wells.

Kauai Island Subregion

Geology

The island of Kauai has an area of about 555 square miles. It is a single large highly-dissected volcano and is composed of two different series of volcanic rocks. The older is the Waimea Volcanic Series and the younger, the Koloa Volcanic Series. Toward the end of the mountain-building phase, the summit collapsed to form a huge caldera in the central part of the shield and a smaller caldera in the southeastern part. Lavas later ponded and filled these calderas and a graben which formed in the southwestern part. These ponded lavas cooled slowly to form massive dense flows in contrast to the thin-bedded flows, which erupted on the flanks of the volcano. A long period of volcanic quiescence and erosion followed, during which time high sea cliffs and deep canyons were formed. After this period, posterosional lava eruptions filled much of the deeply eroded canyons in the eastern half of the island. These later Koloa flows are dense and massive, especially where they were ponded in depressions and deep canyons.

Owing to the wide range in permeability from one volcanic formation to another, and even within the same formation, the ground-water hydrology of Kauai is the most complicated in the Region. In general, the rocks of the Waimea Series are more permeable than those of the Koloa Series.

Coastal-plain sediments are significant on the Mana Plain, at Kapaa, Kealia, and Hanalei. Erosion of both the Waimea and Koloa Series produced large volumes of alluvium at the base of steep mountains and in stream valleys. The sedimentary rocks are at least 500 feet thick at the coast in the Mana Plain, 175 feet thick at the mouth of Hanalei Bay, and 150 feet thick at Kapaa and Kealia.

The surface distribution of the major rock formations are approximately as follows: 1) Rocks of the Waimea Volcanic Series - Napali Formation, 29 percent; Olokele Formation, 16 percent; and Makaweli Formation, 4 percent; 2) rocks of the younger Koloa Volcanic Series, about 44 percent; and 3) coastal sediments and alluvium, the remaining 7 percent.

A geologic map of the island is shown in figure 76. The stratigraphic sequence of the rocks and their water-bearing properties are shown in the following table.

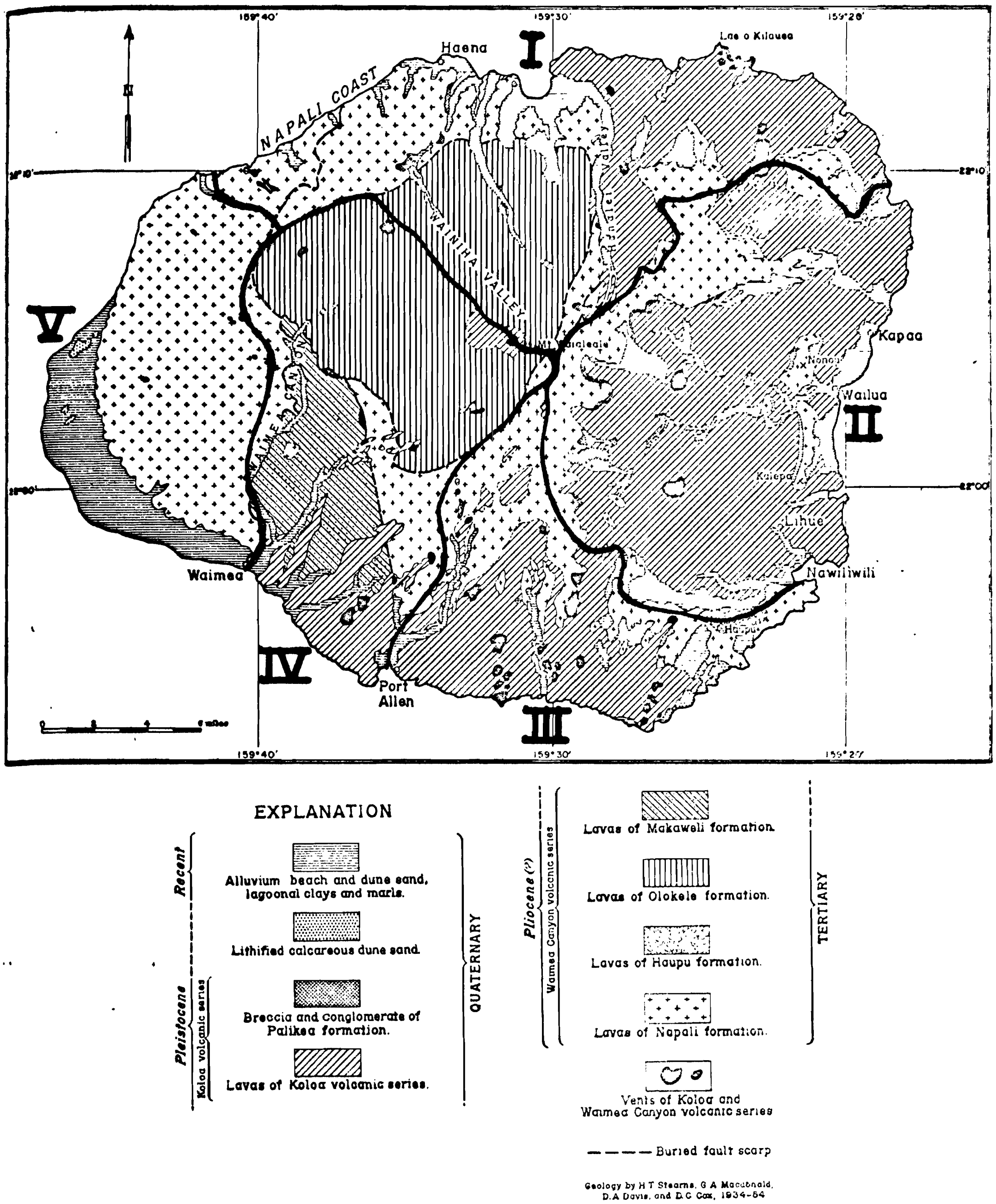


Figure 76. Generalized geologic map of Kauai.

Table 20. Stratigraphic units on the island of Kauai

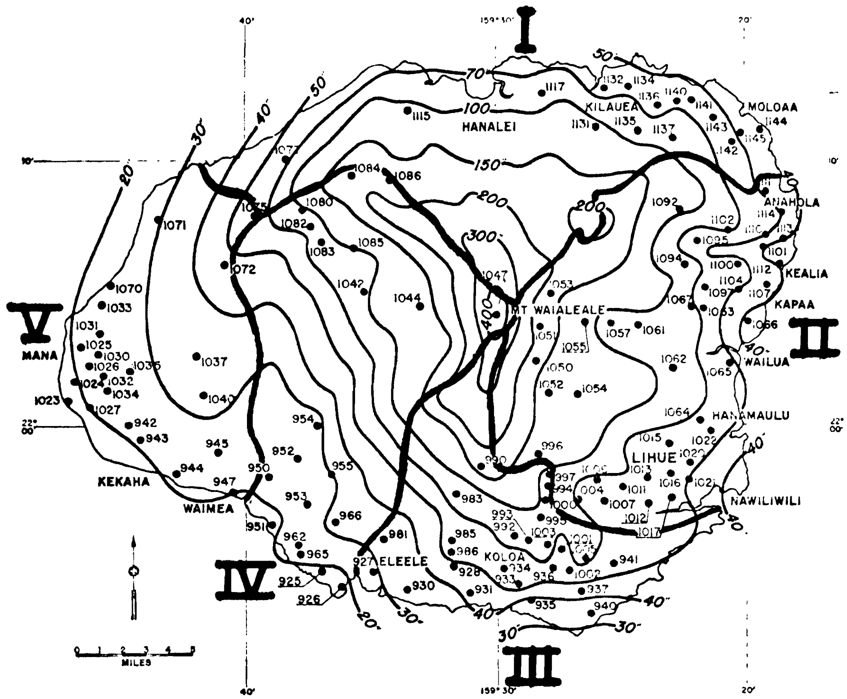
Age	Major geologic unit	Rock assemblage	Thickness (feet)	Symbol on map (pl. 1)	General character	Water-bearing properties
Recent (Holocene)	Sedimentary deposits.	Beach sand.	5±	Rb	Loose sand, composed chiefly of fragments of calcareous algae, corals, mollusk shells, and skeletons of Foraminifera.	Very permeable; carries brackish or saline water at sea level.
		Unconsolidated calcareous dunes.	10-100	Rd	Loose cream-colored crossbedded sand blown inland from the beaches and composed of the same materials.	Very permeable, but almost entirely above water table.
		Younger alluvium.	5-200	Ra	Unconsolidated earthy deposits consisting of loose, poorly to moderately well sorted stream-laid gravel, sand, and silt.	Poorly permeable, but contains small amounts of fresh or brackish water.
Local erosional unconformity						
Pleistocene	Sedimentary deposits.	Noncalcareous sediments: Lagoon deposits of Mana plain.	....	Pl	Poorly consolidated earthy and marly sediments accumulated in a lagoon between the volcanic rocks and the beach ridge.	Poorly permeable, but yield brackish water to wells.
		Noncalcareous sediments: Older alluvium.	100±	Pa	Poorly to well consolidated earthy deposits consisting of stream-laid gravel, sand, and silt.	Poorly permeable, but locally carries small amounts of fresh or brackish water.
		Consolidated calcareous dune sand.	10-100	Pd	Moderately to well cemented crossbedded calcareous sand blown inland from beaches during former lower stands of the sea.	Permeable; contains brackish water at sea level.
Local erosional unconformity						
	Volcanic rocks and associated sedimentary rocks.	Koloa volcanic series: Tuff cone at Kilauea Bay.	350±	Pkt	Moderately to well indurated palagonite tuff containing fragments of basaltic rocks and calcareous reef rock.	Poorly permeable; fractures yield small amounts of fresh water.
		Koloa volcanic series: Ash and tuffaceous soil beds.	1-10	Pka	Fresh to highly decomposed ash and cinder intercalated with lava flows of the Koloa volcanic series.	Locally highly permeable and yield water freely, but mostly poorly permeable and locally perch small bodies of fresh water.
		Koloa volcanic series: Cinder cones.	25-250	Pkv	Heaps of fresh to highly decomposed cinders at vents of lava flows of the Koloa volcanic series.	Moderately to highly permeable, but too small to be important aquifers.
		Koloa volcanic series: Palikea formation.	2-700	Pkp	Masses of poorly sorted breccia and beds of poorly to moderately well sorted conglomerate at the base of, or intercalated with, rocks of the Koloa volcanic series.	Poorly permeable; locally perches small bodies of fresh water.
		Napali formation.	2,700+	Twn	Thin flows of olivine basalt, basalt, and picrite-basalt accumulated on the flanks of the Kauai shield volcano.	Highly permeable; carries fresh water at sea level over much of the island, and yields it freely to wells; may contain water confined at high levels between dikes in some areas.

Rainfall

Average rainfall is about 94 inches per year, which is equivalent to 2,430 mgd. This quantity, which amounts to an average rainfall of 4.4 mgd per square mile, is the highest in the State. Rainfall on the nearly circular island is symmetrically distributed in general; the maximum occurs near the centrally located summit area and the minimum along the coast. An exception is the Mana Plain which is comprised of a bulge of sedimentary rocks protruding from the main volcanic mass. The lowest rainfall on the island, less than 15 inches per year, occurs along this coast.

Most of the rainfall in the wetter mountainous areas is the result of precipitation from the cooling of moist trade-wind air, as it rises over the central mountain mass. Most of the rainfall along the coast is the result of infrequent Kona storms. Because Kona storms are more common during the winter months, the coastal areas are wetter in the winter than in the summer. The rainfall in the wet mountainous areas is more evenly distributed throughout the year.

Figure 77 shows the distribution of rainfall and rain gages compiled by the National Weather Service. Shown also in figure 77 is a comparative monthly distribution of rainfall of selected gages, which was compiled by Macdonald, Davis, and Cox (1960).



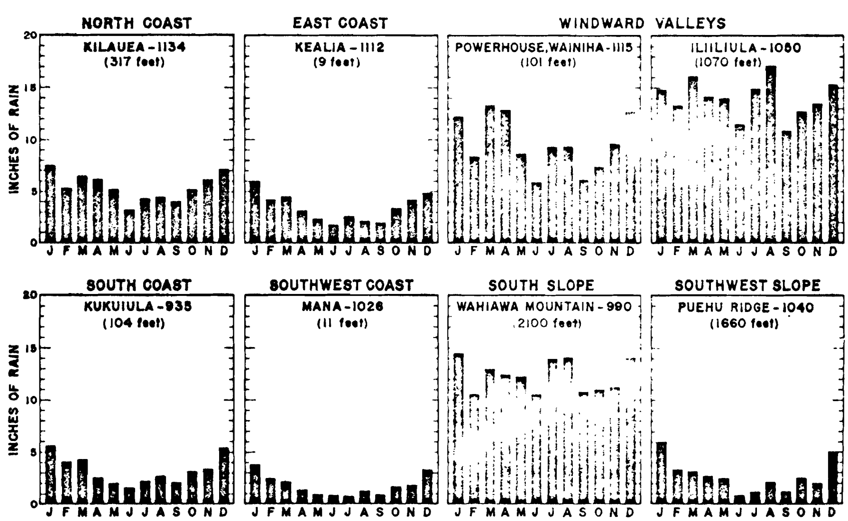


FIGURE 77. AREAL DISTRIBUTION OF RAINFALL, KAUAI.

Surface Water

Abundant rainfall and geologic history have produced conditions such that there is more surface runoff from Kauai than from any other subregion. Large streams radiate from a central swampy highland and perennial streams occur in all parts of Kauai except the southwestern area between Waimea River and Milolii Stream. Low flow of the streams is maintained by persistent rainfall in the mountains and by discharge from high-level springs and seeps.

More than 90 percent of the water developed for use on the island comes from surface-water sources. Extensive systems of ditches and tunnels are used to transport the water long distances from rainy source areas to drier use areas for the irrigation of sugarcane.

Development of hydroelectric power is also greater on Kauai than on the other islands because of the availability of surface water at high elevations.

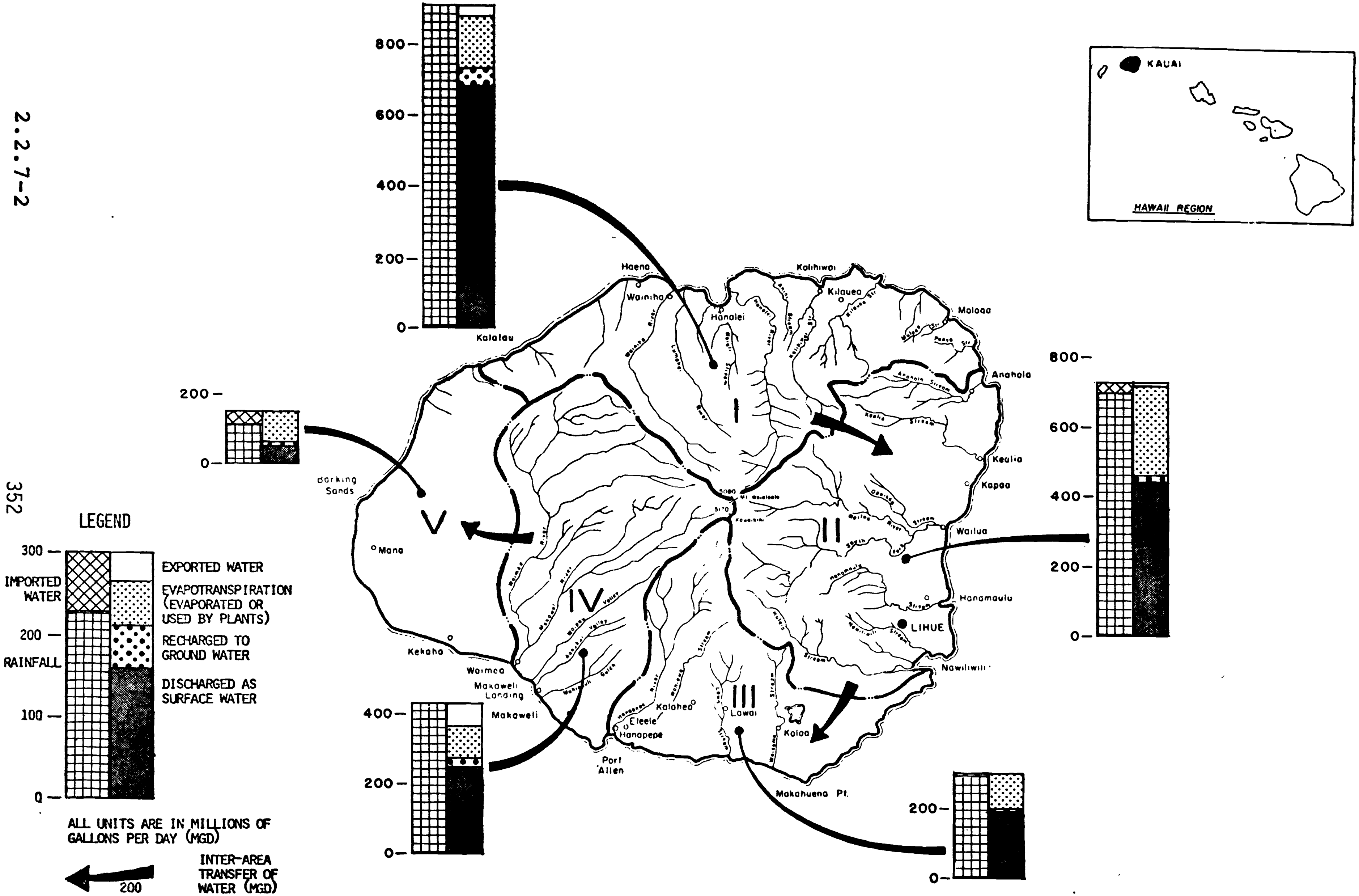
Ground Water

Ground water occurs as basal water, as dike-impounded water, and as perched water. It is, however, almost impossible to discuss the occurrence and movement of water in Kauai without indicating or treating water occurring in or on rocks of the Waimea Volcanic Series separately from that occurring in or on rocks of the Koloa Volcanic Series. Owing to the great differences in hydrologic properties, especially that between the Napali Formation of the Waimea Series and the Koloa rocks, the water in these rocks can be considered to be in two distinct hydrologic systems. In many places where the Koloa rocks have been deeply ponded in depressions and deep canyons, the permeability may be so low that there may be little or no transfer of water between the Koloa and Napali rocks.

Pumpage from ground-water sources averages about 85 mgd. Of this amount, about 73 mgd is pumped from the basal water underlying the Kekaha-Mana area, nearly all of it for the irrigation of sugarcane. Ground-water sources supply about 3.5 mgd of water for domestic use in Kauai. A U.S. Geological Survey study of the water resources of the Kekaha-Mana area (Burt, 1975) indicates that the pumping rate, which averaged 73 mgd in 1972 and 1973, may be in excess of the recharge rate by a significant amount. Continued pumpage at this rate will cause further increase in the intrusion of seawater into the ground-water body. Elsewhere on the island, pumpage has not been high enough to induce significant seawater encroachment.

On Kauai, the underflow discharge of ground water to the sea is only a small fraction of that which discharges as streamflow.

A rough accounting of the disposition of rainfall on the island of Kauai is shown in figure 78. Water developed for irrigation, unless exported out of or imported into an area, is not accounted for. Water used for irrigation, including that of ground water is combined with evapotranspiration.



SUBREGION 7
ISLAND OF KAUAI

FIGURE 78. WATER OCCURRENCE, KAUAI.

Table 21. Disposition of Rainfall

Island of Kauai
(Units in mgd)

Area	Rainfall	Evapotranspiration	Runoff	Ground-water flux
I	910	160	687 a/	45
II	710	237 b/	444 c/	36
III	280	75	195	10
IV	414	100 d/	245 e/	25
V	116	105 f/	58	8

a/ Does not include 18 mgd exported to Area II.

b/ Includes 18 mgd imported from Area I.

c/ Does not include 11 mgd exported to Area III.

d/ Includes 11 mgd imported from Area II.

e/ Does not include 55 mgd exported to Area V.

f/ Includes 55 mgd imported from Area IV.

<u>Quality of Water</u>

Surface-Water Quality

Surface water on Kauai has a very low mineral content and is chemically suitable for most uses. The average dissolved-solids concentration is 63 mg/l. Water from Waialae Stream, at altitude 3,820 feet, has less than 20 mg/l dissolved solids, and has characteristics similar to that of rainwater.

The average hardness-of-water is 29 mg/l. The water is low in salinity, and is suitable for all irrigation purposes. Chloride concentration seldom exceeds 20 mg/l.

Silica content is low. The average concentration is 13 mg/l. This suggests that Kauai's surface waters do not contain much ground-water outflow.

Nutrients are not detected in any significant amounts. Huleia Stream has nitrate-nitrogen concentration ranging from 0.1 mg/l to 0.5 mg/l. Concentration greater than 0.1 mg/l is seldom detected in water samples analyzed for most other streams.

Turbidity is high during periods of peak flow, and is attributed mostly to runoff from agricultural lands.

Color content of Waialae Stream water ranges from 20 to 120 platinum units. This water comes from Alakai Swamp, and is diluted by high rainfall in the area.

Kauai's perennial streams have excellent development potentials for recreational fishing. The physical, chemical, and biological qualities of stream waters are well suited for the stocking of trout and bass.

Figures 79 through 82 give the ranges and average concentrations of dissolved solids, hardness, chloride, and silica for selected streams on the island of Kauai.

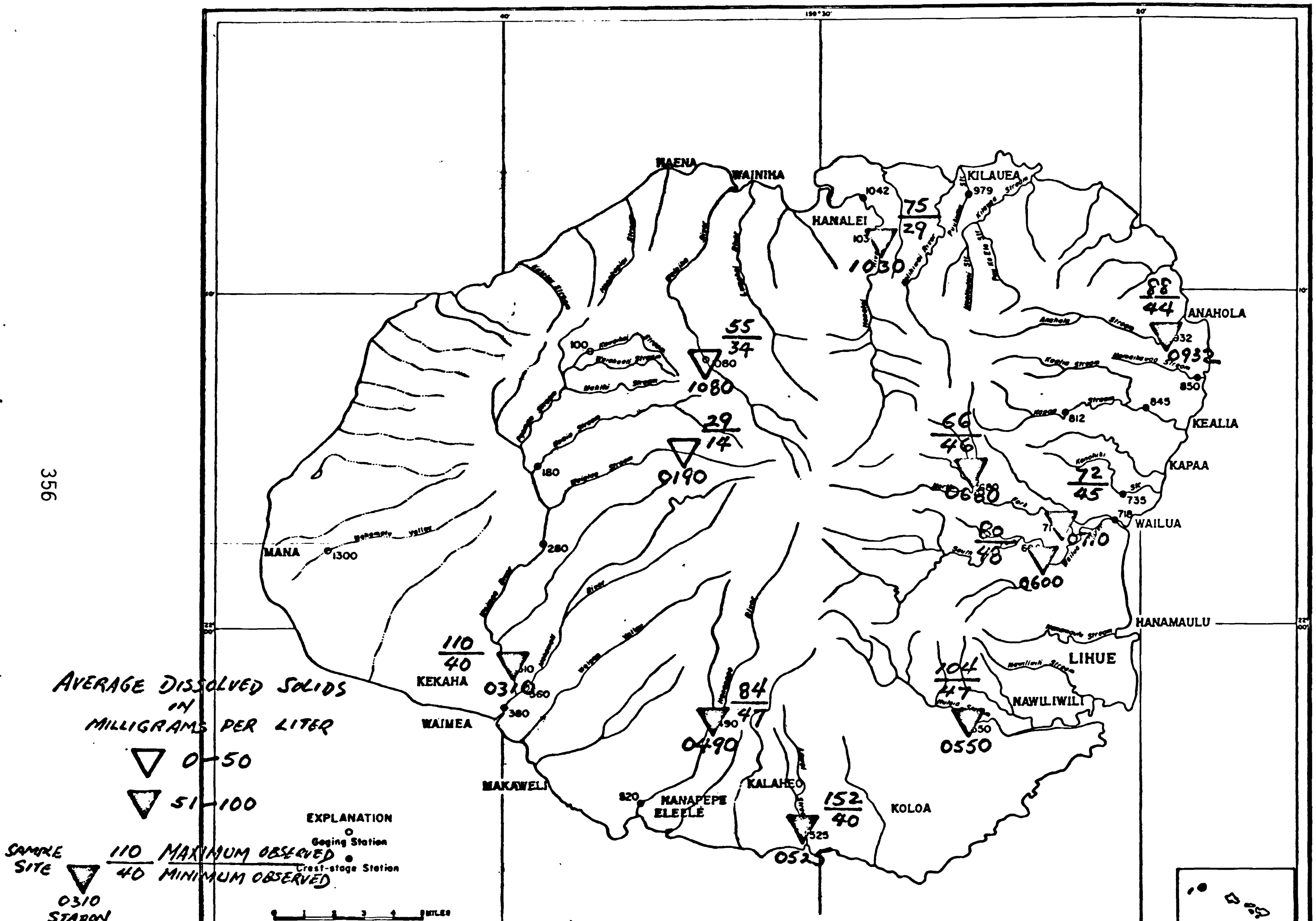


Fig. 79. RANGE AND AVERAGE DISSOLVED-SOLIDS CONCENTRATION IN SELECTED STREAMS

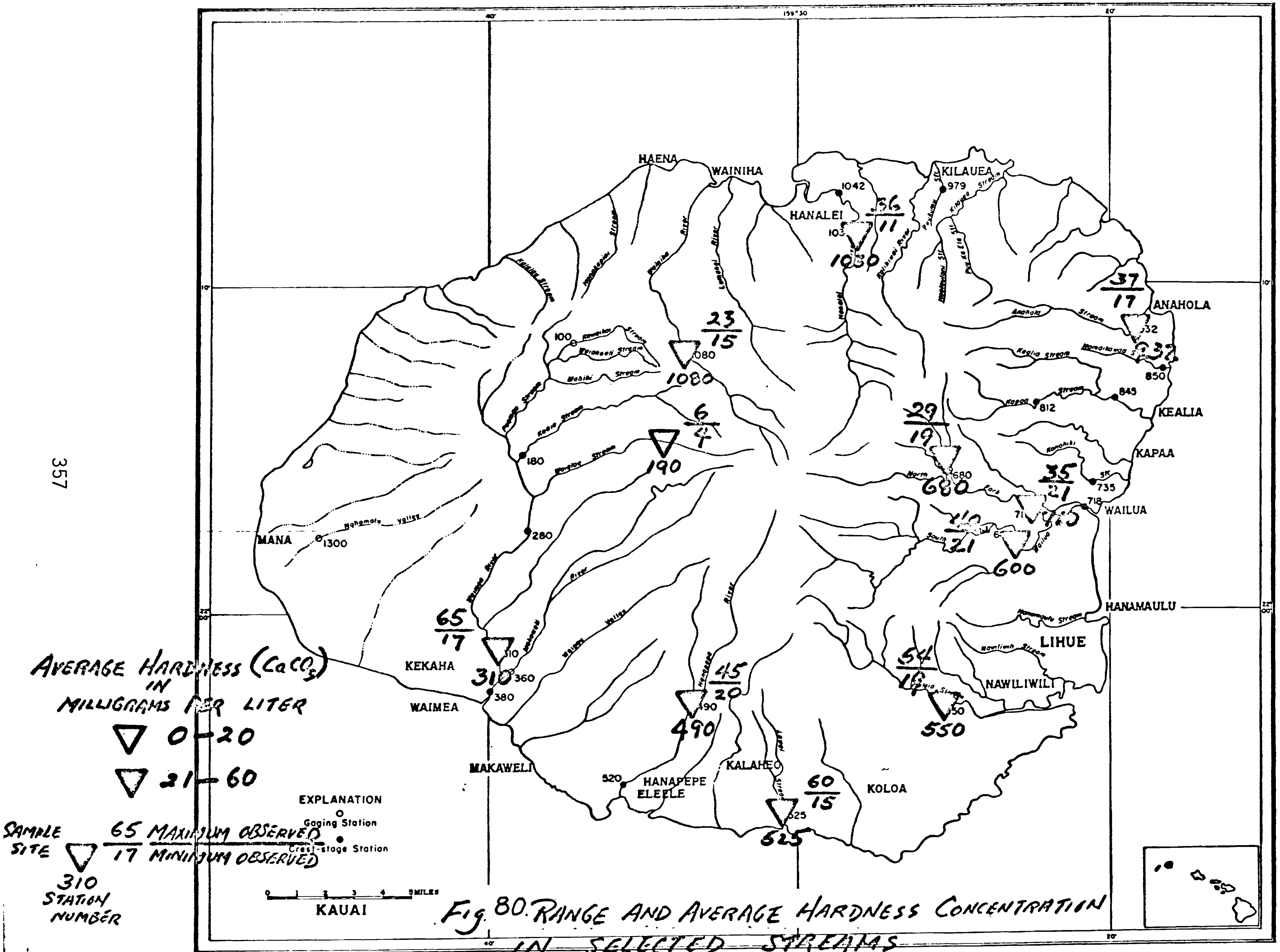


Fig. 80. RANGE AND AVERAGE HARDNESS CONCENTRATION IN SELECTED STREAMS

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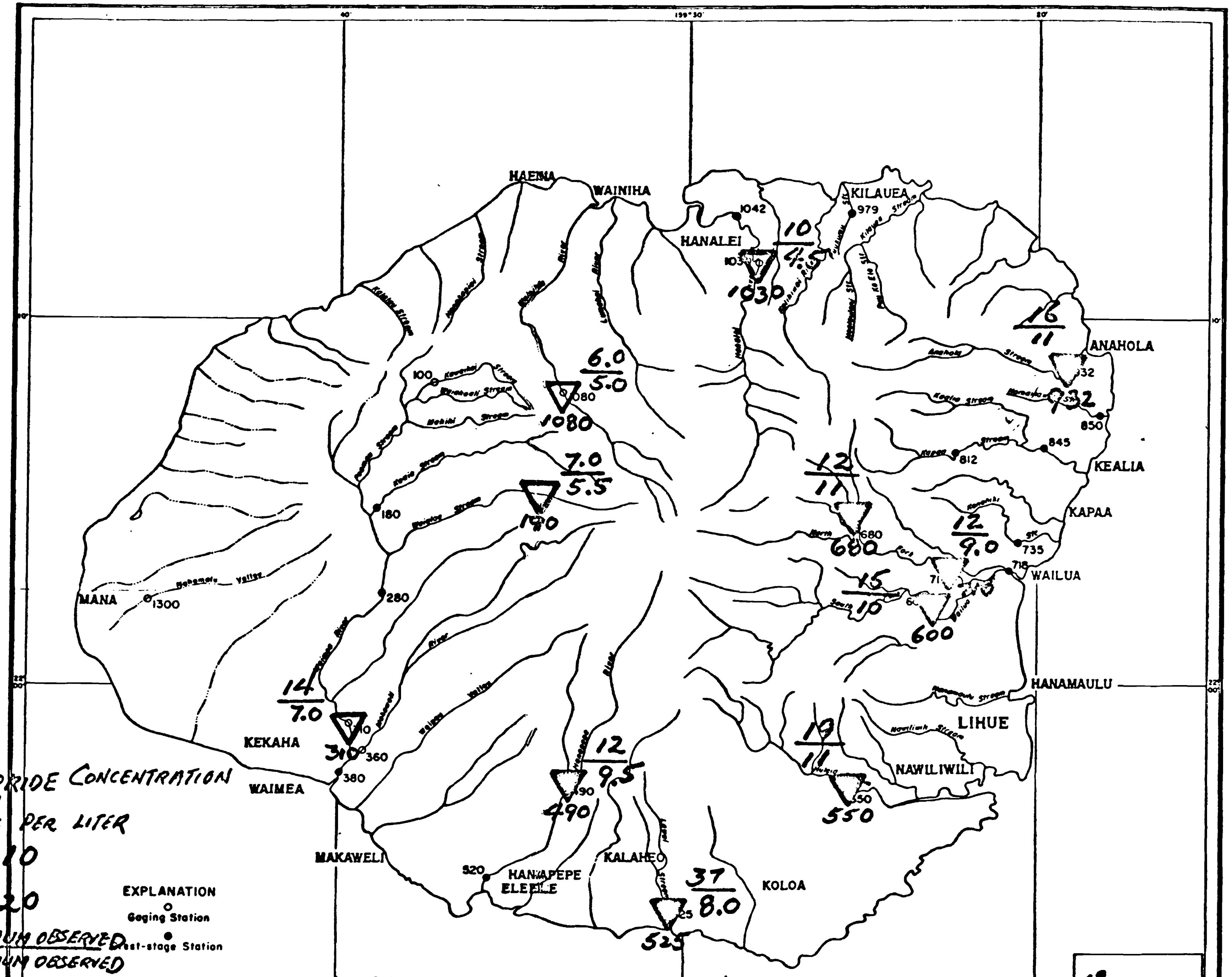


AVERAGE CHLORIDE CONCENTRATION IN MILLIGRAMS PER LITER

▽ 0-10

▽ 11-20

SAMPLE SITE ▽ 14/7.0 MAXIMUM OBSERVED / MINIMUM OBSERVED

310 STATION NUMBER

Fig 81. RANGE AND AVERAGE CHLORIDE CONCENTRATION IN SELECTED STREAMS

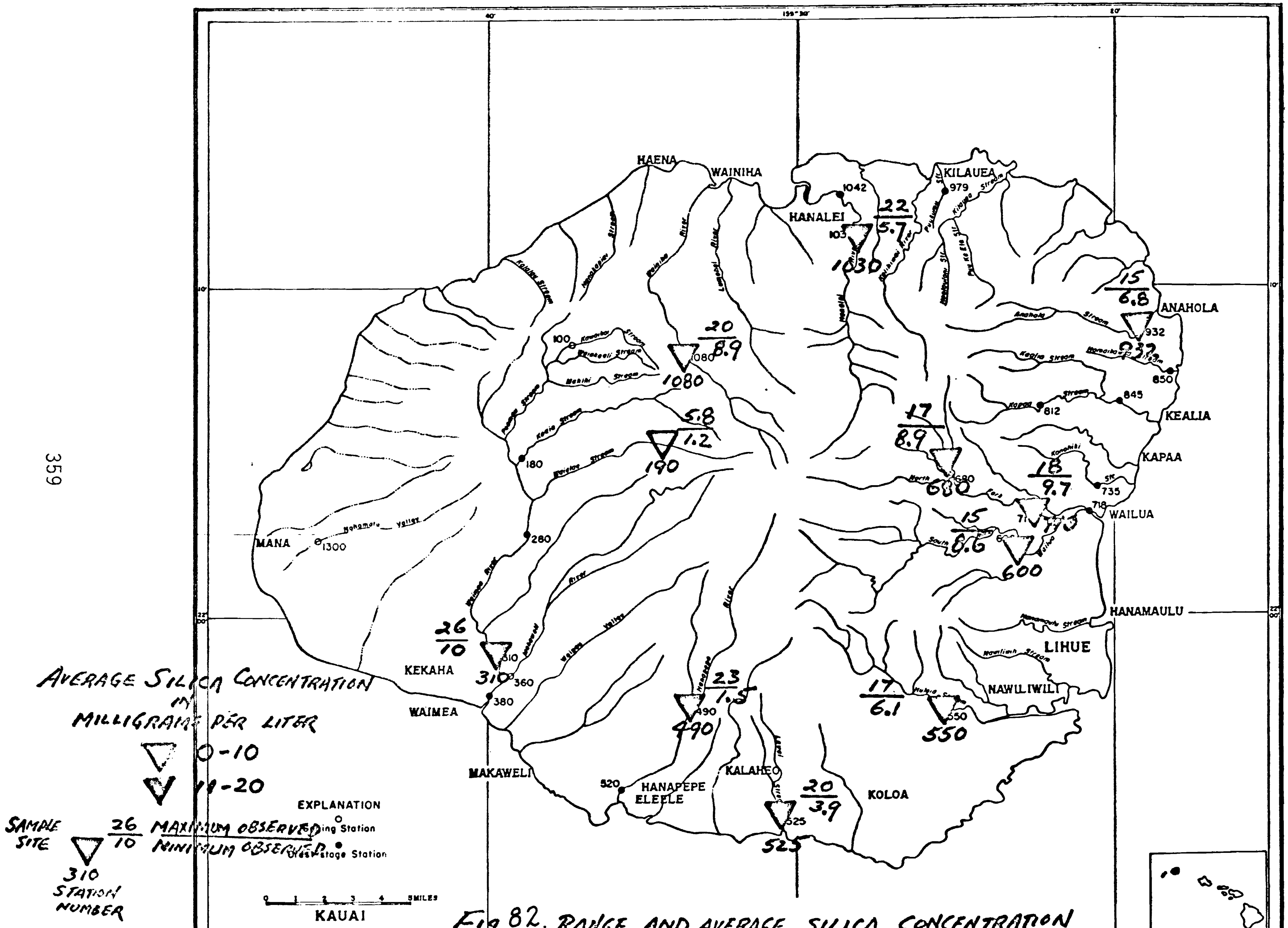


Fig 82. RANGE AND AVERAGE SILICA CONCENTRATION ~~IN SELECTED STREAMS~~

Ground-Water Quality

The overall chemical quality of ground water is excellent. Dissolved-solids content seldom exceeds 300 mg/l and most of the chloride concentrations range from 10 mg/l to 50 mg/l. An exception is in the western coastal plains area where seawater has intruded the basal aquifer.

Perched and dike waters are predominantly of the magnesium-sodium-bicarbonate type, and have low dissolved-solids concentration. Basal water varies considerably. Bicarbonate is the major anion, except where seawater intrudes; chloride ion is then the predominant anion.

Area I

This area is about 138 square miles in area and comprises the north slope of the main volcano and that part of the caldera area which drains to the north.

Geology

The end of the mountain-building phase was marked by summit collapse to form a huge caldera in the central part. Lavas ponded and filled the caldera before spilling over into a graben depression in the southwestern rim of the caldera wall.

The northern coast area includes the northern slope of the main volcano and that part of the lava-filled caldera which now drains to the north. A long period of volcanic quiescence and erosion followed the caldera-filling phase, during which time high sea cliffs and deep canyons were formed. The sea battered the coast to form broad shelves backed by a cliff of bare rock 3,000 feet high in places. The island slowly submerged and streams in the deep valleys deposited their sediment load and filled the valley floors with alluvium. After this period, posterosional lava eruptions (Koloa rocks) filled much of the deeply eroded canyons in the northeastern part of the area.

The flank flows, the Napali Formation, are generally thin-bedded and highly permeable. The caldera-filling flows (Olokele Formation) were ponded and so are usually dense and poorly permeable, as are the Koloa rocks, which ponded in deep canyons and depression.

The total thickness of the alluvium in the drowned valleys, notably Hanalei, Lumahai, and Wainiha, is unknown but may be several hundred feet. A well drilled near the mouth of Hanalei Valley encountered lava at a depth of 167 feet.

Rainfall

Most of the rain that falls in this area results from the cooling of warm, moist trade-wind air, as it is lifted orographically. The heaviest rainfall on the island, more than 400 inches per year, occurs near the summit crest at Waialeale. Rainfall decreases toward the shore, more rapidly toward the eastern and western shores than toward the northern shore. Annual rainfall is about 40 inches along the northeast and northwest shores and about 70 inches on the north shore (fig. 77). On the basis of this rainfall map, rainfall was computed to average 139 inches per year or an equivalent of about 910 mgd.

Surface Water

In this area are located several of Kauai's largest surface-water discharges into the ocean. Except for the not-too-extensive irrigation diversions in the Kilauea area (now discontinued), the diversion of 18 mgd from Hanalei River to the Wailua basin, and other small diversions, all surface water arising in the area flows out to sea. Extensive taro plantings are irrigated in Hanalei Valley, and about 42 mgd passes through the hydroelectric plant at Wainiha before returning to the stream.

Measured streamflows in the various parts of the subarea are listed below:

Measured and estimated streamflow in northern area

	Mgd
Puukaele and Moloaa Stream diversions	
Kaloko ditch	3.7
Puukaele ditch	3.1
Pohakuhonu Stream	5.2
Kalihiwai ditch	2.6
Halaulani Stream	7.5
Kalihiwai River	31.0
Hanalei River	150.0
Hanalei Tunnel	18.0
Waioli Stream	20.0
Lumahai River	75.0
Wainiha River	185.0 [1/]
Hanakapiai Stream	11.0
Hanakoa Stream	3.5
Kalalau Stream	4.5
Total	520.1

1/ Rose T. Davis, 1960, "Major Streams of Kauai and Their Utilization," M. S. Thesis, Univ. of Hawaii.

Ground Water

Ground water occurs as basal water, as perched water, and as dike-impounded water. The principal aquifer is the Napali Formation and the principal mode of occurrence, with reference to developable supplies, is basal water.

Koloa lava flows underlying the broad, gently sloping surface between Hanalei Bay and Anahola generally have poor permeability. These rocks contain both perched-water and basal-water bodies. Perched-water bodies are probably not large nor widespread. Principal ground-water occurrence in these rocks is as basal water where they extend below sea level.

The caldera-filling Olokele Formation is not an important aquifer owing to its generally low permeability and remoteness.

The quality of ground water in all the water bodies is generally excellent. One exception is the water from Moloaa tunnel 3, a source of domestic water for two consumers, where water having a nitrate content of 66 mg/l has been collected. This water body is perched in Koloa lavas at an altitude of about 250 feet. The source of the nitrate is apparently irrigation water return from sugarcane field lying inland above the tunnel.

Figure 83 shows the location of wells and tunnels. The chloride content and water levels from selected wells are also shown.

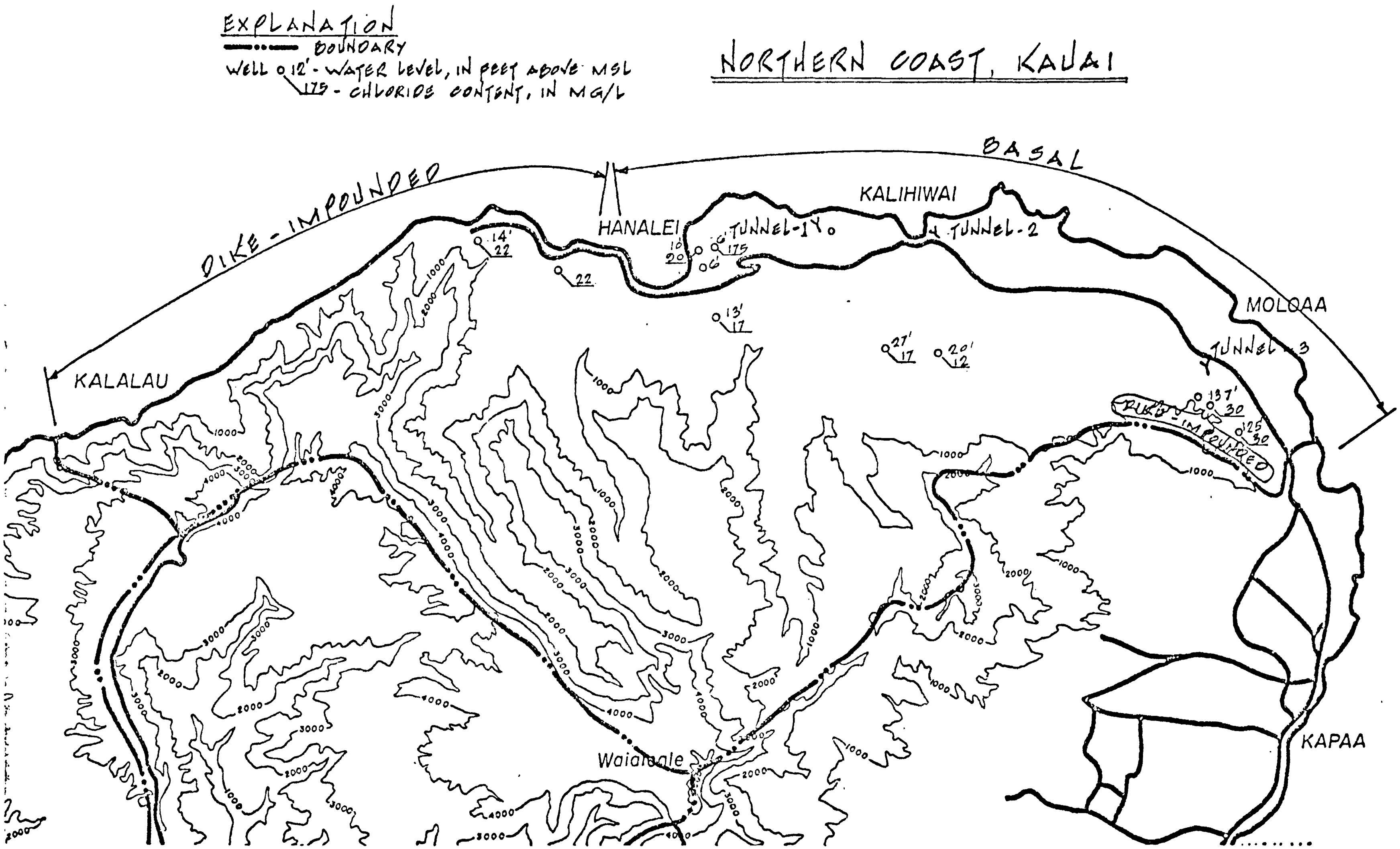


FIGURE 83. MAP SHOWING LOCATION OF WELLS AND TUNNELS.

Basal Water

Basal water in the principal aquifer, the Napali Formation, occurs under both water-table and artesian conditions. It is unconfined or under water-table conditions wherever dike-free Napali Formation crops out at the surface. It occurs under artesian conditions where overlying Koloa rocks or poorly permeable sediments act as a confining member. Basal water generally occurs in the Hanalei area and in the area east of Hanalei.

Basal water in Koloa lavas occurs under water-table conditions. At least two wells near Hanalei Bay have been drilled into this water body. Yields in these and other wells tapping the Koloa aquifer are usually low but these wells are valuable sources of ground water for isolated or small developments.

The principal aquifer, the Napali Formation, is recharged by infiltration of rainfall and surface runoff, by underflow from dike-impounded water bodies, and by discharge from perched-water bodies, especially those overlying the Napali aquifer in Koloa rocks. The aquifer is discharged by pumping, and by underflow to sedimentary rocks, to the Koloa rocks, or to sea. Where water levels in the Koloa rocks stand higher than in Napali rocks, it may be possible to induce additional water into the Napali Formation by lowering water levels in the Napali by pumping.

The probability exists that the Koloa rocks are, for the most part, totally impermeable in the vertical section. If this is the case, little or no water can be transferred to or from the underlying Napali Formation.

Dike-Impounded Water

Dikes intruding lava flows of the Napali Formation along the Napali coast prevent the occurrence of basal water, except in small bodies. Some ground water probably discharges near sea level along the Napali coast, largely from dike-impounded water bodies that have been breached by marine or stream erosion. The Napali Formation between Napali coast and Hanalei Bay, is also intruded by dikes in the coastal areas, but in much of the area, sedimentary rocks overlie the Napali Formation. The sedimentary rocks retard the seaward flow of ground water and causes ground-water levels to stand at high levels near the coast.

East of Hanalei Bay, the Napali Formation is overlain by a wedge of poorly-permeable Koloa lavas. Much of the ground water in coastal areas occurs in basal-water bodies, but dike-impounded water bodies are not uncommon a few miles inland. Wells drilled 2 miles inland--southwest of Moloaa Bay--show water levels of 125 to 137 feet above mean sea level. The water body tapped by these wells is probably dike-impounded.

Perched Water

Perched-water bodies occur extensively in Koloa rocks, but most of these bodies probably are discontinuous and small. They are not likely sources for large supplies of water but may be important local sources for small supplies.

Present Use of Water

Surface Water

Except for irrigation water diverted from streams near Kilauea (reduced in amount since the end of sugar cultivation) and some water diverted from Hanalei River to the Wailua River basin, the only major use of surface water in this area is for the generation of hydroelectric power at Wainiha. Ample water is available for the cultivation of the remaining taro lands in Hanalei.

Ground Water

Pumpage of ground water in 1973 was about 1.2 mgd. Of this amount, slightly more than 1 mgd was pumped for sugarcane irrigation, and the remainder, slightly less than 0.2 mgd, was pumped for domestic use.

All of the water for irrigation use was pumped from two wells in the Papaa area, tapping an apparent dike-impounded water body in the Napali Formation. About 0.2 mgd was pumped from wells tapping basal water in the Napali Formation in the Hanalei and Haena areas. In addition, about 3,500 gallons per day was derived from tunnels tapping perched-water bodies in Koloa rocks at Kalihiwai, Anini, and Moloaa.

Potentials for Development

Surface Water

Surface water is available in amounts in excess of present needs in this area. Large unused quantities flow to sea in the larger streams such as Hanalei, Lumahai, and Wainiha. In other areas, streamflow--while not in as large quantities--is also greater than required for local use.

Ground Water

The best potential for developing ground water is from water bodies in the Napali Formation. Development would mostly consist of wells tapping dike-impounded water bodies west of Hanalei Bay, in the Papaa area, and in other inland areas east of where the Napali Formation is dike-intruded. Most wells in coastal areas east of Hanalei Bay would probably tap basal-water bodies. Both dike-impounded and basal ground water occur under artesian conditions wherever they are confined by Koloa lavas or by sedimentary rocks of low permeability.

Computations of streamflow and rainfall input in selected basins show that at least 75 to 80 percent of the rainfall in the area is diverted to streams. The streamflow versus rainfall-input percentage ranges from about 65 percent west of Wainiha Valley to about 85 percent east of and including Wainiha Valley. Thick sedimentary or Koloa lava sections underlie much of the stream channels in the eastern area, whereas in the area west of Wainiha Valley, these low-permeable rocks are much less abundant.

A rough accounting of the dispositions of rainfall is given below:

	Mgd		Percentage of input	
	Range	Average	Range	Average
Input				
Rainfall -------------		910		100
Output				
Surface runoff -------	680-730	705	75-80	77.5
Exported to eastern coast area, 18 mgd				
Evapotranspiration ---	135-180	160	15-20	17.5
Underflow to ocean ---	0- 90	45	0-10	5.0
Total output ---------		910		
Underflow per shoreline mile ------		1.5		

If lowering the ground-water level in the principal aquifer by pumping can reduce streamflow in stream channels cutting the Napali Formation or the Koloa and the sedimentary sections, the potential of developing ground water is much larger than the 45 mgd indicated by the rough water budget.

As in other areas underlain by Koloa rocks, the probability exists that these rocks are totally impermeable in the vertical section. If this is so, little or no water enters or leaves the Napali Formation from or to Koloa rocks.

Area II

This area of about 145 square miles comprises the eastern slope of the main volcano and the Lihue depression, which is filled with younger Koloa lavas.

Geology

Following the mountain-building and caldera-filling phases, there occurred a long period of volcanic quiescence and erosion, during which time high sea cliffs and deep canyons were formed. After this period, posterosional (Koloa) lava flows ponded and filled much of the deeply eroded and alluviated canyons.

The rocks of the rugged mountains and ridges are generally from lava flows of the Napali Formation, which are thin-bedded and highly permeable in contrast to the ponded Koloa flows. The more gentle slopes bordering the mountains are composed of lava flows of the Koloa Volcanic Series.

The Lihue depression, a nearly circular basin, lies in the southern part of this area. Two vents of the Koloa Volcanic Series lie within the basin, which is filled with Koloa rocks.

Deposits of partly consolidated calcareous dune sands occur along the east coast near Kalepa Ridge. Beach deposits consisting of calcareous sands form discontinuous deposits between Hanamaulu and Kealia.

Figure 76 shows the distribution of rock types in Kauai.

Rainfall

The high rainfall in the mountainous area is the result of cooling of moist trade-wind air, as it flows upward over the high mountains and occurs throughout the year. Along the coast, most of the rainfall is the result of Kona storms, which are more frequent in the winter months and more uniformly distributed areally.

Average rainfall is about 103 inches per year, which is equivalent to about 710 mgd.

Surface Water

Streams are perennial in this area and despite large diversions for irrigation, all major streams still discharge into the ocean.

Huleia Stream, measured at an altitude of about 200 feet, has had an average recorded flow of about 18 mgd (1912-15, 1967-70).

The principal stream in the area is Wailua River. Even below diversions an average of 77 mgd flows in the South Fork, at altitude 240 feet, above Wailua Falls. An average of 87 mgd flows in the North Fork, at altitude 18 feet.

About 18 mgd is brought into this basin from Hanalei through the Hanalei tunnel and about 11 mgd is taken out of the basin into the Koloa area through Koloa ditch and Koloa tunnel. Wailua ditch diverts about 9 mgd to irrigate sugarcane fields above Kapaa. Other ditches, including Upper Lihue Ditch, Lower Lihue Ditch, and Hanamaulu Ditch, divert about 59 mgd for irrigation of fields within and southward of the Wailua basin.

Surface water in the Wailua basin amounts to:

South Fork below diversions ------------------------		77 mgd
North Fork below diversions ------------------------		87
Koloa ditch and tunnel (outflow) -----------------	11 mgd	
Wailua ditch (outflow) ---------------------------	9	
Hanalei tunnel (inflow) --------------------------	(-18)	
Net ---		2
Opaekaa Stream ------------------------------------		2
		168 mgd
Used within basin ---------------------------------		59
Total ---		227 mgd

Kapaa River, below diversions at altitude 377 feet, flows at an average amount of about 14 mgd. About 4 mgd is diverted from Kapaa River by Kapahi Ditch and Makaleha ditch diverts about 4 mgd from Makaleha Stream, a tributary of Kapaa River.

Anahola Stream, at the old highway crossing, flows at an average of 27 mgd below diversions of about 3 mgd by Anahola ditch and about 2 mgd by Lower Anahola ditch.

Measured flow in eastern Kauai amounts to:

Huleia basin -----------	18 mgd
Wailua basin -----------	227
Kapaa basin ------------	22
Anahola basin ----------	32
Total ------------------	299 mgd

Ground Water

Ground water occurs as basal water, as perched water, and, most likely, as dike-impounded water. The principal aquifer is the Napali Formation, but important sources of basal water have been developed in the Koloa Formation by wells drilled at Anahola, Kealia, and Kapaa.

Dike-impounded water in the Napali Formation is probably more abundant near the coast in the northern part than in the central or southern part. The Haupu, Kalepa, and Nonou Ridges in the southern and central parts appear to be isolated from the rainy mountains by deep sections of Koloa lava fills. In the northern part, Puu Ehu Ridge and ridges in the Makaleha Mountains are generally less isolated.

Water perched on soil, ash, or dense lava flows occurs widely in Koloa rocks.

The quality of ground water is generally excellent, except for the water from wells drilled close to the shore in the Koloa rocks.

Figure 84 shows the location of wells, tunnels, and shafts. Water levels and the chloride content of selected wells are also shown.

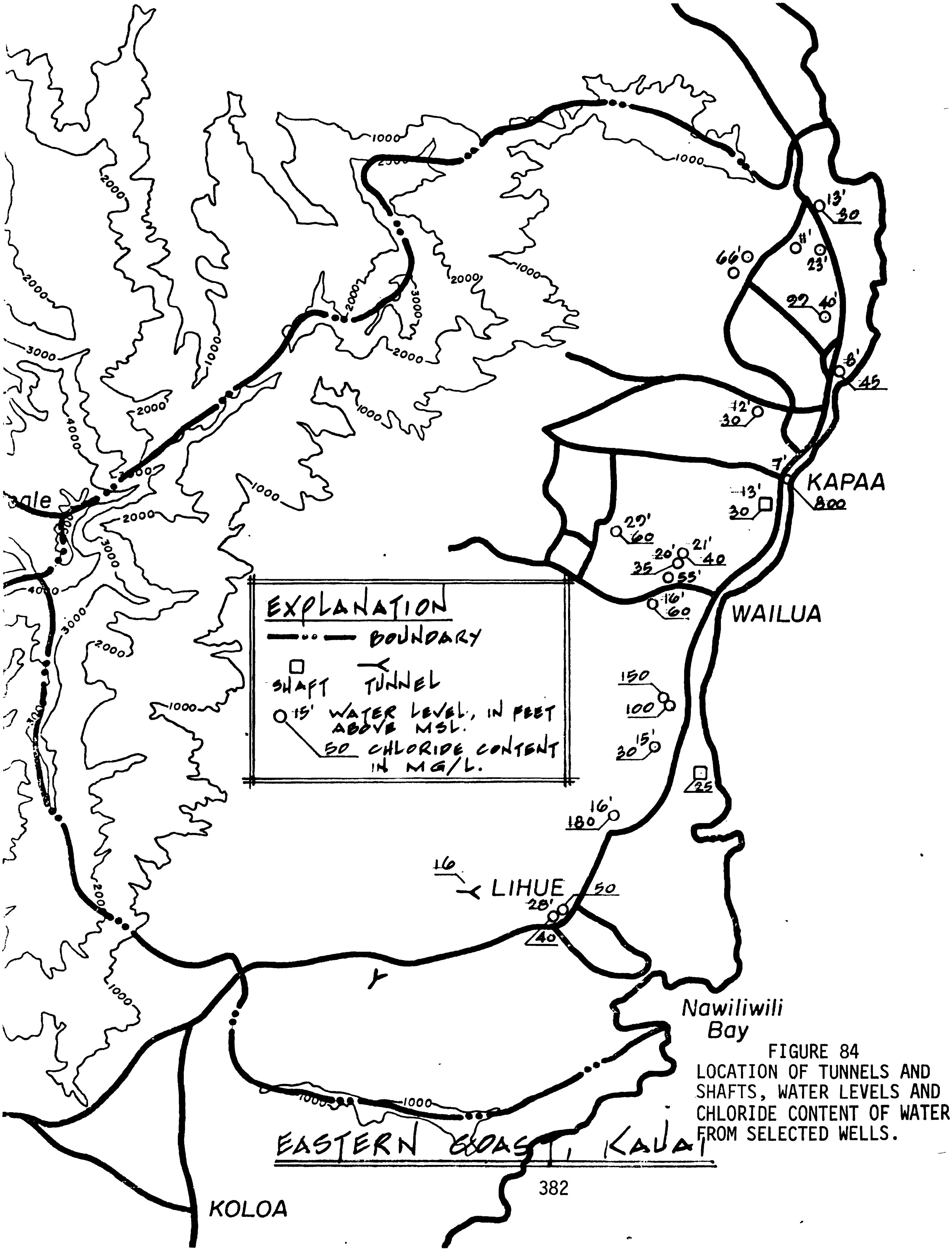


FIGURE 84
LOCATION OF TUNNELS AND SHAFTS, WATER LEVELS AND CHLORIDE CONTENT OF WATER FROM SELECTED WELLS.

Basal Water

Anahola to Wailua.--Basal-water levels in the Napali Formation are relatively high owing to the confining or impounding effect of Koloa rocks, which overlie or are banked against the Napali rocks. Basal water in the Napali Formation probably discharges into the Koloa rocks, in which the heads are lower than those in the Napali Formation. The highest basal-water levels in wells occur in the easternmost ridge of the Makaleha Mountains, where they are at least 66 feet above msl.

Basal water occurs in Koloa rocks in the coastal areas where water levels are generally less than 10 feet above mean sea level. Water has been developed by wells at Anahola, Kealia, and Kapaa. Pumpage is about 0.5 mgd.

Wailua to Nawiliwili (Lihue District).--Basal water occurs in the Napali Formation in Kalepa Ridge, in most of Haupu ridge, and in Nonou ridge.

Wells in Kalepa Ridge have heads ranging from 10 to 16 feet. Heads in Nonou ridge range from 15 to 30 feet. No wells have been drilled in the Haupu ridge except at Kipu Kai, where the head is 5 feet, and the water has a chloride content of about 60 mg/l. Yields of all these wells are small. The reason may be that these ridges are hydrologically isolated from water bodies in the Napali Formation that are recharged in the rainy mountainous area.

Two wells have been drilled to tap the basal-water body in the Koloa rocks. One is 745 feet deep or about 520 feet below sea level, where it terminates in a formation of coral and sand. The well yielded 375 gpm with a drawdown of about 60 feet. The water temperature is about 76°F, which suggests that most of the recharge to the water body is local and not in the high-mountainous area. The chloride content of the water from the well pumped was about 40 mg/l. The yield of this well may be typical of other wells drilled into Koloa lavas in the Lihue depression. Yields may be better for wells drilled in the northern part, outside the Lihue depression, where the Koloa lavas may be less ponded and, subsequently, more permeable.

Dike-Impounded Water

Anahola to Wailua.--Much of the ground water identified as basal water in the ridges of Makaleha Mountains and Puu Ehu ridge may be partially dike-impounded. This could account for the high heads measured in wells.

Streams flowing from the Makaleha Mountains are probably fed partly by the discharge of dike-impounded water bodies.

Wailua to Nawiliwili (Lihue District).--As in the area between Anahola and Wailua, much of the ground water identified as basal water in the isolated ridges may be partially dike-impounded.

A large amount of high-level water, some of it dike-impounded, discharges into streams from the Napali Formation that makes up the west wall of the Lihue depression. The occurrence is, however, not favorable for easy development. No large springs that would encourage development by tunnels are evident.

Perched Water

Anahola to Wailua.--Streams flowing from the Makaleha Mountains are partly fed by the discharge of perched-water bodies. The flow of three large springs has been developed for domestic use by tunnels.

Small perched-water supplies in the Koloa rocks are developed by a short tunnel near Anahola.

Wailua to Nawiliwili (Lihue District).--Perched-water bodies on soil, ash, or dense lava occur widely in Koloa rocks. Most are small, but in a few places, they occur in quantities adequate for municipal supplies. One of the tunnels (Tunnel 8) supplies about 1.2 mgd of domestic water. The water is perched on red clay.

Present Use of Water

Surface Water

Surface-water diversions account for nearly all the water used in the irrigation of sugarcane lands in this area. While about 18 mgd is diverted into the area from the northern coast through Hanalei tunnel, some water is taken out of the area into Area III.

Surface water is also used at two hydroelectric plants in the Waiahi Stream basin, and the water passing through the plants is later used for irrigation.

Ground Water

Ground water is developed at a rate of about 1.6 mgd, of which at least 1.2 mgd is for domestic use. Perched water developed by tunnels make up about 70 percent of this total. The remainder, except for about 60,000 gallons per day, is pumped from basal supplies tapping the Koloa aquifer. The 60,000 gallons pumped daily are from the Napali aquifer.

Potentials for Development

Surface Water

The supply of surface water, in general, is in excess to present development and much water that still flows to sea is available for further development, if necessary. Though the trend in the Region is to convert to ground-water sources for domestic water, difficulties in obtaining suitable ground-water sources in the area could result in more use of surface-water sources.

Ground Water

The best potential for developing ground water in coastal areas is from water bodies in the Napali Formation. The northern part of the area, where Napali rocks crop out at Puu Ehu ridge and at ridges of the Makaleha Mountains, appears to be more suitable for development than in coastal areas in the southern part.

The western end of Haupu ridge or the southern slope of the main volcano, where Napali rocks crop out near Knudsen Gap, appear favorable for ground-water exploration.

The Koloa lavas ponded in the Lihue depression in the southern part appear to yield water poorly to wells. Koloa lavas outside this depression appear to be more permeable as in the Kealia, Kapaa, and Anahola areas.

Computations of streamflow and rainfall input in selected basins show that at least 55-70 percent of the rainfall input is diverted to streams as runoff. The streamflow-rainfall input ratio ranges from about 55 percent for the Wailua River basin to about 95 percent for Kapaa Stream basin.

A rough accounting of the disposition of rainfall is given below.

	Mgd		Percentage of input	
	Range	Average	Range	Average
Input				
Rainfall ---------------		710		97
Imported water from northern coastal area ----------------		18		3
Total input ------------		728		
Output				
Surface runoff ---------	400-510	455	55-70	62.5
Evapotranspiration -----	220-255	237	30-35	32.5
Underflow to ocean -----	0- 72	36	0-10	5
Total output -----------		728		
Underflow per shoreline mile -----------------		2		

The potential for further development of ground water in this area is similar to that in other areas on Kauai where Koloa rocks crop out. If lowering the ground-water level in the principal aquifer by pumping can reduce streamflow in channels cutting the Napali Formation or the Koloa or sedimentary rocks, the potential of developing ground water would be much larger than the 36 mgd indicated by the water budget.

On the other hand, the Koloa rocks may be totally impermeable in the vertical section. If so, there would be no transfer of water from or to Napali rocks underlying Koloa rocks.

Area III

This area of about 81 square miles comprises the eastern part of the south flank of the main volcano, and the southern part of the Haupu caldera.

Geology

Towards the end of the mountain-building phase, the summit collapsed to form a huge caldera in the central part of the shield and a smaller caldera in the southeastern part (the Haupu caldera).

Poorly-permeable ponded lava flows in the huge caldera (Olokele Formation) and in the smaller caldera (Haupu Formation). In addition, massive posterosional lava flows of the Koloa Volcanic Series form a thick wedge of mostly poorly permeable rock overlying the permeable flank flows of the Napali Formation. The permeable Napali Formation is dike-intruded in the upper reaches, and in the area of the small caldera in the southeastern part.

Figure 76 shows the distribution of the rock types on Kauai.

Rainfall

The high rainfall in the higher elevations is the result of persistent precipitation from the moist trade-wind air, as it is cooled flowing over the mountain. Trade-wind rainfall is heaviest near the crest and decreases rapidly away from the crest. It occurs throughout the year, but is generally most frequent in the summer, when trade winds are strongest. Most of the rainfall along the coast is the result of Kona storms, which are more uniformly distributed areally.

On the basis of the map shown in figure 77, rainfall in the area was computed to average about 280 mgd.

Surface Water

Hanapepe River, which heads in the eastern end of Alakai Swamp, flows perennially to sea in spite of large diversions, which supply water for sugarcane fields, some of which are outside of this subarea.

At the gaging stations near Koula, Hanapepe River has an average flow of about 55 mgd. From its headwaters, Koula ditch diverts about 25 mgd for the irrigation of lands below the 400-foot altitude westward from Hanapepe River to Kaumakani.

No other streams in the area flow perennially from source to sea. However, the upper reaches of Wahiawa Gulch is perennial and about 10 mgd flows into Alexander Dam, from which about 0.3 mgd is taken for domestic use and the rest used for irrigation of sugarcane lands near Kalaheo and for mill use.

Lawai Stream is perennial in its upper reaches, and at altitude 580 feet, averaged 4.73 mgd for the period 1924-39 (Hirashima, 1941). Domestic-water diversions have been discontinued since the drilling of a deep well (Lawai well 22). Return irrigation water largely maintains the flow at the gaging station, at altitude 37 feet, where records for 1963-72 indicate an average flow of about 5.5 mgd.

	Mgd
Hanapepe Stream diverted	25
below Manuahi Stream	55
Wahiawa Stream	10
Lawai Stream	5
Total	95

Ground Water

Ground water occurs as basal water, as perched water, and most likely as dike-impounded water. The principal aquifer is the Napali Formation. It is the most permeable of the volcanic rocks in this area.

Figure 85 shows the location of wells, tunnels, and shafts. Water levels and the chloride content of the water from selected wells are also shown.

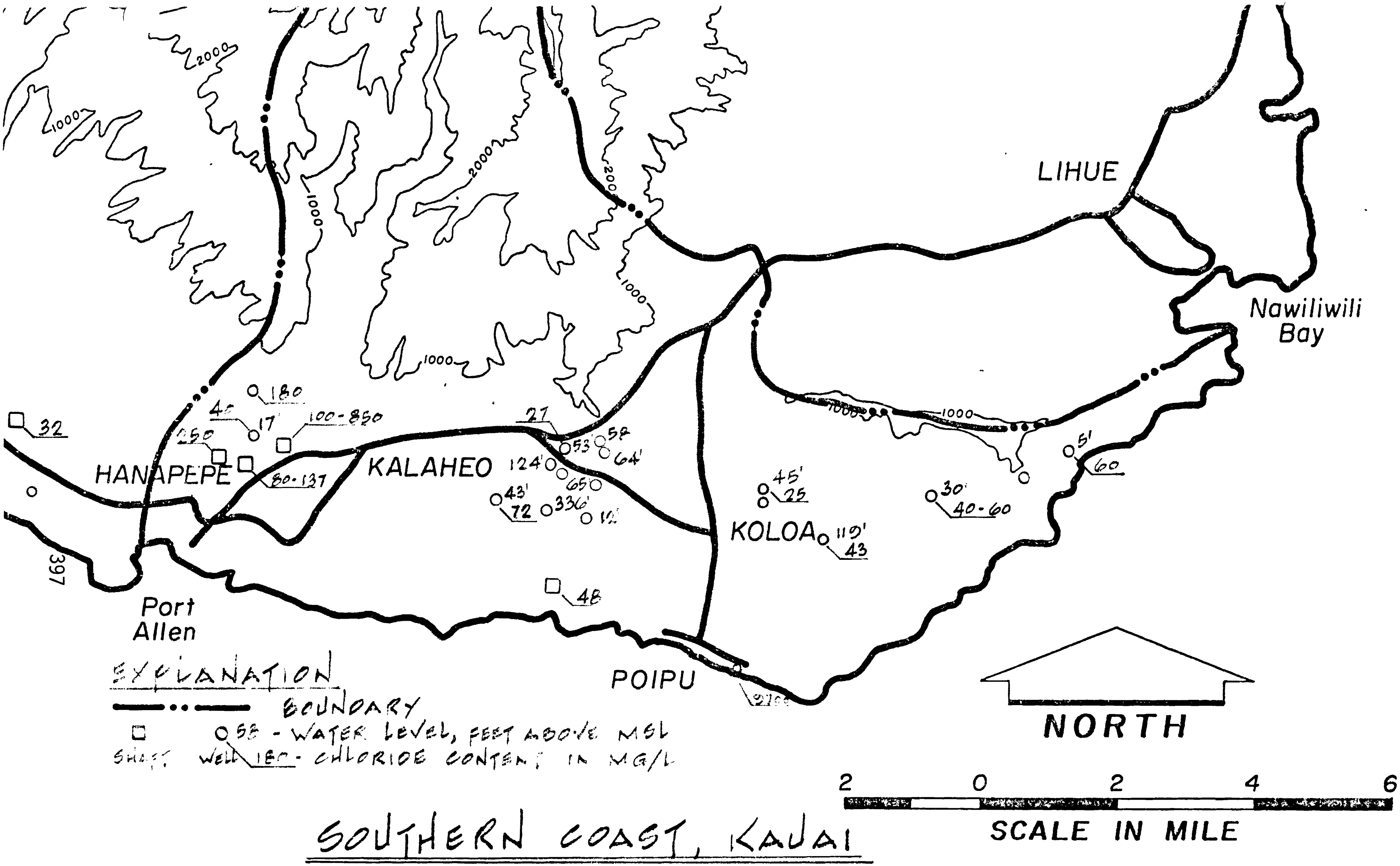


FIGURE 85. MAP SHOWING LOCATION OF WELLS, TUNNELS AND SHAFTS, WATER LEVELS AND CHLORIDE CONTENT OF WATER FROM SELECTED WELLS.

Basal Water

The Napali aquifer, much of it overlain by a wedge of partly saturated, less permeable Koloa lava flows, contains basal water having heads of 5 to 65 feet and chloride contents of 25 to 800 mg/l. The high heads in the basal aquifer are the result of the impounding effects of the rocks of the Koloa Volcanic Series, which lie on the weathered surface of the Napali lavas and which dip seaward. The highest heads occur in the vicinity of Lawai, in the south-central part, and the lowest near the coast at Kipu Kai, in the southeastern part. Much of the basal water in the south-central part, having high heads, occur under artesian conditions. The heads near Lawai stand 60 feet or more above sea level, but the depth to the Napali aquifer is more than 300 feet and increases sharply toward the coast. Because of the steep seaward dip of the eroded surface of the Napali Formation beneath Koloa rocks, basal-water development in Napali rocks near the coast in the south-central part of the area may be costly. The Napali Formation crops out at the coast in the southeastern part where a few wells have been drilled. Away from the coast, the most favorable sites for wells tapping the Napali aquifer are at the ends of Napali Formation spurs.

Basal water in the lava flows of the Koloa Volcanic Series is developed by shafts in the lower valleys of Lawai and Hanapepe Streams. Several wells have also been drilled into this formation. Basal-water levels near the coast are generally less than 20 feet above mean sea level.

Because much of the coastal areas are overlain by a seaward-thickening wedge of poorly permeable Koloa rocks, the discharge of ground water as underflow to sea from the underlying principal aquifer and from the Koloa aquifer is likely to be small.

Dike-Impounded Water

Ground water impounded by dikes may exist in the lavas of the Napali Formation in the south part of the Haupu caldera. The absence of springs at easily accessible sites indicates that the dike-impounded supplies are probably small. Location of dike-impounded water in the rainy mountainous areas would require a search of rugged valleys for springs and the confining dikes.

Dikes are absent or scarce in rock formations other than the Napali Formation.

Perched Water

Perched-water bodies occur in the rocks of the Koloa Volcanic Series in discontinuous bodies, which probably vary greatly in thickness and in areal extent. Numerous seeps and small springs discharge from shallow and generally thin perched bodies that are intersected by stream valleys. In a test boring near Lawai, a perching member at some depth below sea level causes the water level to stand about 360 feet above sea level. Other wells drilled into Koloa lavas indicate perched bodies standing well above basal-water levels in the Napali Formation. The poor permeability of Koloa rocks makes it unfavorable for the development of large supplies of water in perched aquifers.

A tunnel (Tunnel 10) in the valley of the Hanapepe Valley at about an altitude of 196 feet, develops perched water contained in unconsolidated alluvium overlying the weathered surface of the Napali Formation.

Present Use of Water

Surface Water

Large amounts of surface water are diverted mainly for irrigation of sugarcane lands. Diversions include about 25 mgd from Hanapepe River, and about 8 mgd from Wahiawa Gulch.

Surface-water sources had been used for most domestic supplies, but in recent years, these surface-water sources have been replaced almost completely by ground-water sources. Only isolated areas, mostly in the uplands, still rely on surface-water sources.

Hydroelectric power plants have been operated in this area by Grove Farm Co., using water which partly comes from the Lihue area (Area II).

Ground Water

About 25,000 gallons per day is developed by a tunnel tapping a perched-water body in Hanapepe Valley.

Potentials for Development

Surface Water

All feasible surface-water sources are presently being utilized.

Ground Water

The best potential would be to develop ground water in Napali Formation. The Koloa rocks appear to be too heterogeneous and of low overall permeability to allow large development.

As indicated earlier, the most favorable sites for wells tapping the Napali Formation are at the ends of volcanic spurs comprised of these rocks.

Owing to high heads in the Napali Formation, wells can be drilled deep to maximize specific capacities with minimum danger of inducing seawater intrusion. If ground-water flow to stream channels can be reduced by extracting ground water, the potential of developing ground water is large. This would be done only at the expense of reducing streamflow by about the amount developed.

Area IV

This area of about 113 square miles includes the western portion of the central upland and the southern slopes of the main volcano between the west wall of Waimea Valley and the western boundary of the Hanapepe watershed. The Waimea-Makaweli basin makes up most of the area.

Geology

The extent of surface rocks of the Waimea Volcanic Series, Napali Formation, is limited to a small area lying west of Hanapepe River. Caldera-filling flows of the Olokele Formation cover the central upland area. The central portion of the area is covered with flows of the graben-filling flows of the Makaweli Formation. Lavas of the Koloa Volcanic Series form a coastal band with irregular salients projecting northeastward (see fig. 76).

Rainfall

The rainfall in this area ranges from less than 20 inches a year along the coast to more than 400 inches in the mountains near Waialeale. It averages nearly 1,800 mgd.

Surface Water

The one major river basin, the Waimea-Makaweli system, heads in Alakai Swamp and flows perennially to sea despite large diversions which supply water for irrigation of sugarcane both in and outside of this area.

Just above its confluence with its major tributary, the Makaweli River, Waimea River averages about 87 mgd. Diversions averaging 16 mgd take water from its headwaters by Kokee ditch to upland sugar fields located in Area V. About 40 mgd is diverted to irrigate sugarcane land in the lower area of Area V.

The flow of Makaweli River near its mouth averages about 56 mgd. About 45 mgd is diverted far upstream from its main tributary, Olokele Stream, for the irrigation of sugarcane fields in the eastern portion of this area.

Ground Water

Ground water occurs primarily as basal water in both the Napali and Makaweli lava flows of the Waimea Canyon Volcanic Series. The occurrence of ground water in the caldera-filling Olokele Formation has not been explored. Basal water in this Formation probably exists but owing to the poor permeability and remoteness of these rocks, its development does not appear feasible.

The occurrence of ground water in the flows of the Koloa Volcanic Series is generally not predictable.

Basal Water

Basal water in both the Napali and Makaweli Formations in this area occurs with high heads, about 17 feet or more above sea level. These heads are likely the result of the overlying poorly permeable lavas of the Koloa Volcanic Series, which have produced a caprock-like barrier along the coast preventing free discharge of water from the permeable formations to the ocean.

Basal water in the flows of the Koloa Volcanic Series has been developed in places but yields are low.

High-Level Water

Very little water occurs either as dike-impounded or perched water in this area, and while perched water can be found in the rocks of Koloa Volcanic Series, the water bodies are probably discontinuous and of limited value as sources of large supplies.

Present Use of Water

Surface Water

Irrigation systems of Kekaha Sugar Co., Waimea Sugar Co., and Olokele Plantation depend principally on surface-water supplies. About 56 mgd is taken from Waimea River and its tributaries and about 45 mgd is taken from Olokele Stream in the Makaweli River basin for sugarcane. Smaller amounts are diverted in the lower reaches of both Waimea and Makaweli Rivers for the cultivation of taro and other miscellaneous crops.

Ground Water

Ground water in this area is used for domestic purposes wherever feasible in preference to collecting and treating surface water.

Potentials for Development

Surface Water

Increased usage of surface water has been considered, especially in connection with the Kokee Water Project, which proposes, among other things, a 10,500 million-gallon storage reservoir to be formed by a dam on Kawaikoi Stream (Div. of Water and Land Development, 1964).

Ground Water

Additional ground-water supplies can be developed. The most favorable locations for wells are probably in the ends of spurs of the lavas of the Makaweli Formation.

Area V

This area is about 80 square miles in area and comprises the Kekaha-Mana coastal plain and the highland area adjacent to and extending northeast of the coastal-plain area. The highland area is bounded on the east by Waimea Canyon (see fig. 76).

Geology

The area includes the west slope of the large volcano and its bordering coastal plain. The Napali Formation, which represents the early flank flows of the Waimea Volcanic Series, comprises the entire volcanic slope. Scattered, generally east-west trending dikes intrude the Napali Formation in the central and northern part of the area. Although the slope is dissected by numerous narrow and shallow valleys, the ridge-line spurs are relatively uneroded and their slope of about 500 feet per mile probably represents the original lava-flow surface. The seaward margin of the volcanic slope consists of high cliffs truncated by higher stands of the sea in the past and forms the eastern margin of the coastal plain in the central and southern part and sea cliffs in the northern part.

The Kekaha-Mana coastal plain is crescent-shaped and covers about 18 square miles. It has a shoreline length of more than 15 miles and is 2-1/2 miles wide in the central part. The plain is underlain by earthy and marly lagoon deposits, calcareous beach and dune sands, and alluvium derived from the adjacent volcanic highland. The thickness of the coastal-plain sediments ranges from zero thickness at the inner edge to more than 500 feet at the shore. The sediments are underlain by the Napali Formation.

Rainfall

The highest average annual rainfall in this area is slightly more than 50 inches, even though only 10 miles away outside this area, the rainfall is more than 400 inches. The highest rainfall on Kauai occurs in the high mountainous area and is the result of persistent precipitation from the moist trade-wind air, as it is cooled flowing over the mountain. This area receives the tail end of this precipitation in its upper slopes and very little of it in the coastal-plain area. Most of the rainfall in the coastal-plain area and the lower slopes is the result of infrequent cyclonic storms (Kona storms). Because Kona storms are more common during the winter months, the dry leeward slopes are wetter in the winter than in the summer.

On the basis of the rainfall map shown in figure 77, rainfall in the area was computed to average 116 mgd.

Surface Water

While there is some streamflow in the gulches located in the northern end of this area, the quantity is small and insufficient to warrant development, except for limited, local use.

Ground Water

The principal aquifer is the Napali Formation. It is generally highly permeable and carries fresh ground water near and below sea level over much of the area in basal-water bodies. Basal water in the volcanic aquifer occurs under artesian conditions in the coastal-plain area, where the aquifer is overlain by less permeable weathered lava and sedimentary deposits. Some ground water may be impounded by dikes in the inland areas or where the aquifer is dike-intruded near coastal areas. So far, no wells have been drilled which tap dike-impounded ground-water bodies. Owing to the absence of any sizable springs, perched-water bodies appear to be rare and, if present, are likely to be small.

Ground water also occurs in sedimentary deposits in distinct basal-water bodies separated from water bodies in the volcanic aquifer. A few wells tap ground water in the sediments for lawn irrigation and fire control.

Basal Water

Basal ground water in the volcanic aquifer occurs under water-table conditions, except where it underlies poorly permeable sediments in the area of the coastal plain, where it is under artesian conditions. The aquifer is recharged primarily in the volcanic area upgradient of the coastal plain by infiltration of rainfall, surface runoff, irrigation water, and by leakage from unlined irrigation ditches. The aquifer is discharged by pumping, by underflow to the sedimentary caprock, and by evapotranspiration. There probably is little or no recharge as underflow into the area owing to the depth of Waimea Canyon, which forms the eastern boundary. There is also little or no discharge as underflow to the ocean owing to heavy pumping of drainage ditches to the ocean, which keeps water levels low in the sedimentary caprock.

In a recent study yet unpublished on the "Availability of Irrigation Water for the Kekaha-Mana Coastal Plain," R. J. Burt of the U.S. Geological Survey made the following estimates of major components of the hydrologic system before and after irrigation development in the area bordered by the coastal plain.

Estimates of Major Components of the Hydrologic System

in the Kekaha-Mana Area Bordered by Coastal Plain

(All figures in mgd)

	Before development, prior to 1900		After development, 1958-68 period	
		Recharge to aquifer		Recharge to aquifer
Input				
Rainfall				
Volcanic slope -------	66		66	
Coastal plain --------	17		17	
Diversions into area ---	0		55	
		22		38
Total input ------------	83		138	
		Discharge of aquifer		Discharge of aquifer
Output				
Evapotranspiration -----	60		85	
Excess water in coastal plain pumped or flowing to ocean ---------	21		53	
Underflow to ocean -----	2		0	
		To caprock		To caprock
		22		14
		Pumped		Pumped
		0		24
Total output -----------	83		138	

There is no ground-water development in the northern part of the area not bordered by the coastal plain. Recharge to ground water is by the infiltration of rainfall and discharge of ground water is by underflow leakage to the ocean and to stream channels where they are cut below ground-water levels. A rough accounting of the disposition of rainfall is given below.

Estimates of Major Components of the Hydrologic System in the Area not Bordered by Coastal Plain

Input	Mgd
Rainfall	33
Output	
Evapotranspiration	20
Surface runoff	5
Ground-water discharge	8
Total	33

Development of ground water by means of drilled wells in the volcanic aquifer underlying the coastal plain probably began in the early 1880's. By about 1906, 50 or more wells have been drilled throughout the coastal plain for the irrigation of rice and sugarcane. The last of the wells in the coastal plain were drilled in 1929 and 1930. Development of basal water by development shafts along the inland edge of the coastal plain began in 1931 and by 1957, six shafts were installed. In 1966, 1967, and 1970, wells near and above the coastal plain were drilled near Waimea, Kekaha, and the mouth of Kaulaula Valley, respectively.

The discharge of ground water has shifted from the coastal-plain area to near and above the inland edge of the coastal plain. Pumpage of ground water increased from about 5 mgd during the 20-year period, 1920 to 1940, to about 12 mgd for the period 1940 to 1958 and to about 24 mgd for the period 1958 to 1968. In 1972 and 1973, average pumpage tripled to about 73 mgd. Most of the pumpage prior to 1940 took place in the coastal-plain area. After this period, most pumpage moved inland above the plain. Concurrent with the shift in pumpage inland, natural discharge of ground water in the coastal-plain sediments and leakage from leaky casings declined owing to lowered ground-water levels underlying the plain. Artesian heads have declined from levels of 10 to 12 feet above sea level in the early 1900's to 2 to 6 feet above sea level in recent years. Even though natural ground-water discharge may be reduced to zero, it is likely that pumpage at a rate averaging 73 mgd exceeds the recharge rate of ground water. If this overdraft condition continues, seawater intrusion of the aquifer will also continue.

The shift in pumpage from the coastal plain to inland areas has accelerated the intrusion of seawater into the volcanic aquifer underlying the coastal plain. Presently, the water from most of the wells in the coastal-plain area does not meet the drinking water standards recommended by the Public Health Service.

Figure 86 shows the location of wells, irrigation ditches, and water levels and chloride content of the water from selected wells in the area.

Present Use of Water

Ground Water

Basal water is pumped from wells and shafts, mostly near the inland edge or above the coastal plain. Pumpage in 1973 was about 73 mgd; of this amount about 1 mgd is pumped for domestic use and the remainder for the cultivation and processing of sugarcane.

A few drilled wells tap basal water in the sedimentary caprock for lawn irrigation and fire control.

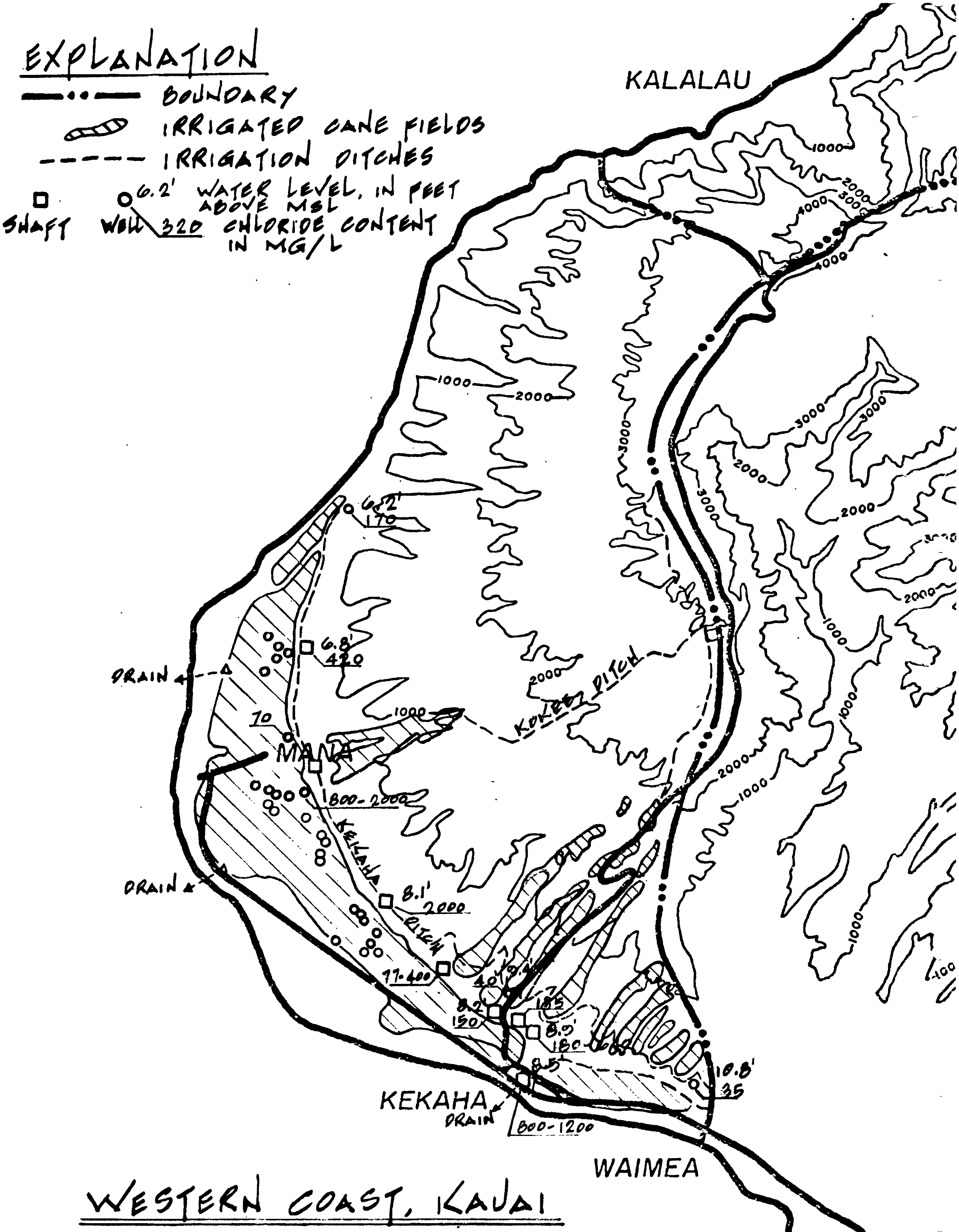


FIGURE 86. LOCATION OF WELLS, IRRIGATION DITCHES, AND WATER LEVELS AND CHLORIDE CONTENT OF WATER FROM SELECTED WELLS.

Potentials for Development

The U.S. Geological Survey study indicates pumping rates which averaged 73 mgd in 1972 and 1973 may be in excess of recharge rates by a significant amount. Most of the pumpage in 1972 and 1973 were from shafts at the inner edge of the control plain. They intercept ground water that would otherwise discharge naturally seaward, therefore pumping at this rate probably induces seawater to intrude the volcanic aquifer underlying the coastal plain. Continued pumpage at a rate higher than the recharge rate will eventually cause the water in the shafts currently pumped to become salty. The overpumpage situation could be relieved significantly by increasing the import of Waimea River water specifically for recharging the aquifer in the volcanic slopes.

Locally, untapped domestic-quality basal water is available in the northern part of the area not bordered by the coastal plain and in the southern part near Waimea.

Niihau Island Subregion

Geology

Niihau is a deeply eroded remnant of a volcanic dome, whose lower slopes have been covered by late posterosional volcanics. The island has two major geomorphic provinces; the uplands or the upper flanks of the eroded dome, and the lowlands, a coastal plain averaging about 75 feet in altitude but containing numerous playa lakes only slightly above sea level. The uplands are covered with about 5 feet of red soil, which is underlain by 20 to 50 feet of partly decomposed basalt. The lowlands consist of the posterosional volcanics, consolidated and unconsolidated dunes, alluvium, and beach sand.

Rocks of the Paniau Volcanic Series, make up the volcanic dome. The flows are mostly thin-bedded olivine basalt and basalt. Numerous dikes, mostly trending northeast-southwest, cut the remnant dome. Rocks of the Kiekie Volcanic Series form the coastal plain. The lavas of this Series are massive and thick-bedded.

The distribution of the rock units are shown in figure 87. The stratigraphic sequence of the rocks and their water-bearing properties are shown in the following table.

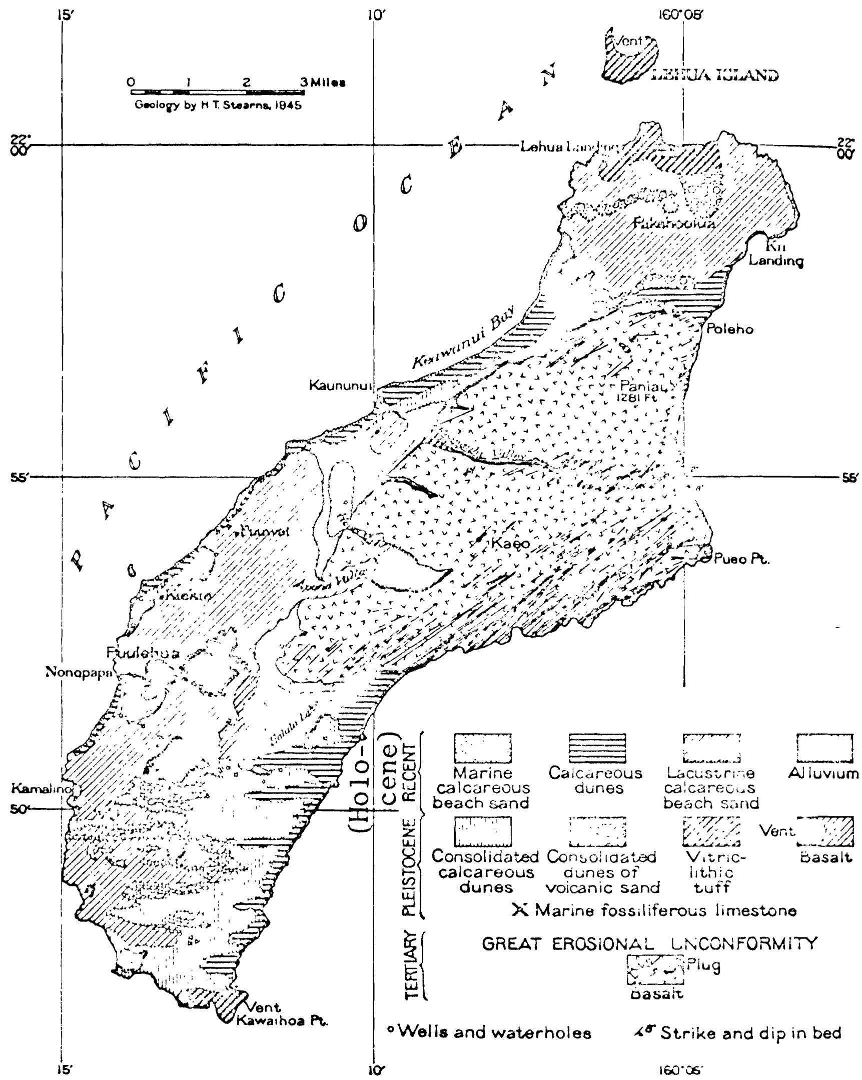


Figure 87. Geologic map of the island of Niihau. The Pleistocene basalts are named the Kiekie volcanic series and the Tertiary basalts are the Paniau volcanic series.

Table 22. Stratigraphic rock units on the island of Niihau

Major geologic unit	Rock assemblage	Thickness (feet)	Symbol on map (pl. 1)	General Character	Water-bearing properties
(Holocene) Recent sedimentary rocks	Unconsolidated calcareous marine beach sand	10±	Rs	Beach sand composed of grains of worn coralline algae, molluscs, and lesser amounts of coral. Skeletons of foraminifera and other marine organisms are locally abundant.	Very permeable and usually contains brackish water at sea level.
	Unconsolidated calcareous dunes	10-120	Rd	Fine-grained cross-bedded cream-colored sand blown inland from the present beaches or derived from older partly lithified dunes.	Very permeable and commonly contain small quantities of potable water.
	Weakly consolidated lacustrine beach sand	8±	Rls	Exceedingly fine-grained calcareous dune sand blown into Halalii Lake from the adjacent sea beaches and subsequently formed into beach ridges by the lake.	Fairly permeable but probably would yield slightly brackish water.
	Unconsolidated earthy deposits	5-50±	Ra	Chiefly younger alluvium consisting of loose, poorly sorted, poorly rounded, stream-laid brown silt, sand, and gravel. Includes talus fans at the foot of cliffs and extensive playa deposits of brown silt and red lateritic transported soil derived from the uplands in historic time.	Poorly permeable but yield small supplies of brackish water near the ephemeral lakes.
Local erosional unconformity					
Late Pleistocene sedimentary rocks	Consolidated emerged marine deposits	1-12	X	Small outcrops of fossiliferous emerged reef and beach limestone.	Too small to carry water.
	Consolidated calcareous dunes (eolianite)	10-150	Pd	Consolidated and partly consolidated calcareous dunes consisting of thin-bedded and cross-bedded eolian limestone composed of pale yellow uniform grains of sand blown inland from beaches during and since the minus 60-foot stand of the sea.	Permeable and yield small quantities of water for stock to dug wells.
	Consolidated dunes of volcanic sand	10-150	Pvd	Consolidated and partly consolidated thin-bedded and cross-bedded dunes of black and brown sand composed chiefly of basalt, basaltic glass, and olivine derived from ash from the Lehua Island vent.	Poorly permeable but might yield small quantities of potable water at sea level to wells far from the coast.
Local erosional unconformity					
Pleistocene volcanic rocks (Kiekie volcanic series)	Vitric-lithic tuffs in Lehua and Kawaihoa cones	5-700+	Pt	Gray to brown well-bedded deposits of vitric-lithic tuff and beds of tuffaceous breccia containing angular blocks of older tuffs, lavas, and reef limestone. The beds are generally cemented by calcite and are partly altered to palagonite. They form cones near the vents but are thin elsewhere.	Poorly permeable but supply perched seeps on Kawaihoa cone and potable water to dug wells at sea level near Lehua Landing.
	Lava flows	20-300+	Pb	Dense and vesicular pahoehoe lava flows of olivine basalt that issued from 6 secondary cones. Those on the north and south ends of the island carry little soil; the others carry 2± feet of lateritic soil.	Very permeable and yield small quantities of water for stock to dug wells.
	Cones	300±	Pc	Secondary cones of thin-bedded highly vesicular lava containing a few dense layers, usually with spatter at the summit.	Highly permeable, except one which has a crater filled with soil and alluvium and serves as a reservoir.
Great erosional unconformity					
Tertiary volcanic rocks (Paniau volcanic series)	Basaltic lava flows with a few thin ash beds, cut by numerous dikes	1200+	Tb	Lava flows forming a dome of thin-bedded basaltic aa and pahoehoe. The flows are 1 to 50 feet thick and were laid down in rapid succession. The lava issued from hundreds of dikes ½ to 17 feet thick trending SW-NE. A few vitric ash beds generally less than 1 foot thick are interbedded with the basalts.	The basalts are extremely permeable, but they yield only small quantities of water because rainfall is low and they are cut into many small compartments by the dikes. A few seeps issue from the tuff beds.

Rainfall

Niihau is semiarid, sheltered, in part, from the moist trade-wind air by Kauai. Occasional southerly (Kona) winds bring heavy downpours, which are usually widespread. Naulu or convective-type showers sometimes bring relief to parts of the island during hot weather.

Average annual rainfall on the island ranges from less than 20 inches at its southern tip to more than 40 inches near the top of the dome on the eastern shore. The annual mean is about 26 inches, which is equivalent to 88 mgd.

Surface Water

There are no perennial streams on Niihau, and except when occasional rains result in some runoff, the waters in the playa lakes are brackish.

No potential large-scale development of surface water is foreseen.

Ground Water

The ground-water map (fig. 88) shows the occurrence of ground water and the location of the principal water sources.

The domestic water supply is from rain caught on roofs and catchments. Only a few wells yield water with chloride content less than 260 mg/l. Most wells and water holes are brackish.

Basal Water

Basal water occurs in all rock units that extend below sea level and is the principal source of water on the island. Only a few wells yield water of domestic quality in limited amounts. The prospects are poor for developing large domestic-quality supplies. Numerous wells yield water fit for cooking, washing, and stock, and by proper development and limited draft, additional supplies of such water could be developed. The total quantity of recoverable water is small and amounts to thousands instead of millions of gallons per day. This, according to Stearns (1947), results from low rainfall, adverse geologic structures, and large quantities of salt carried inland by spray, and the presence of salt crystals in many rocks.

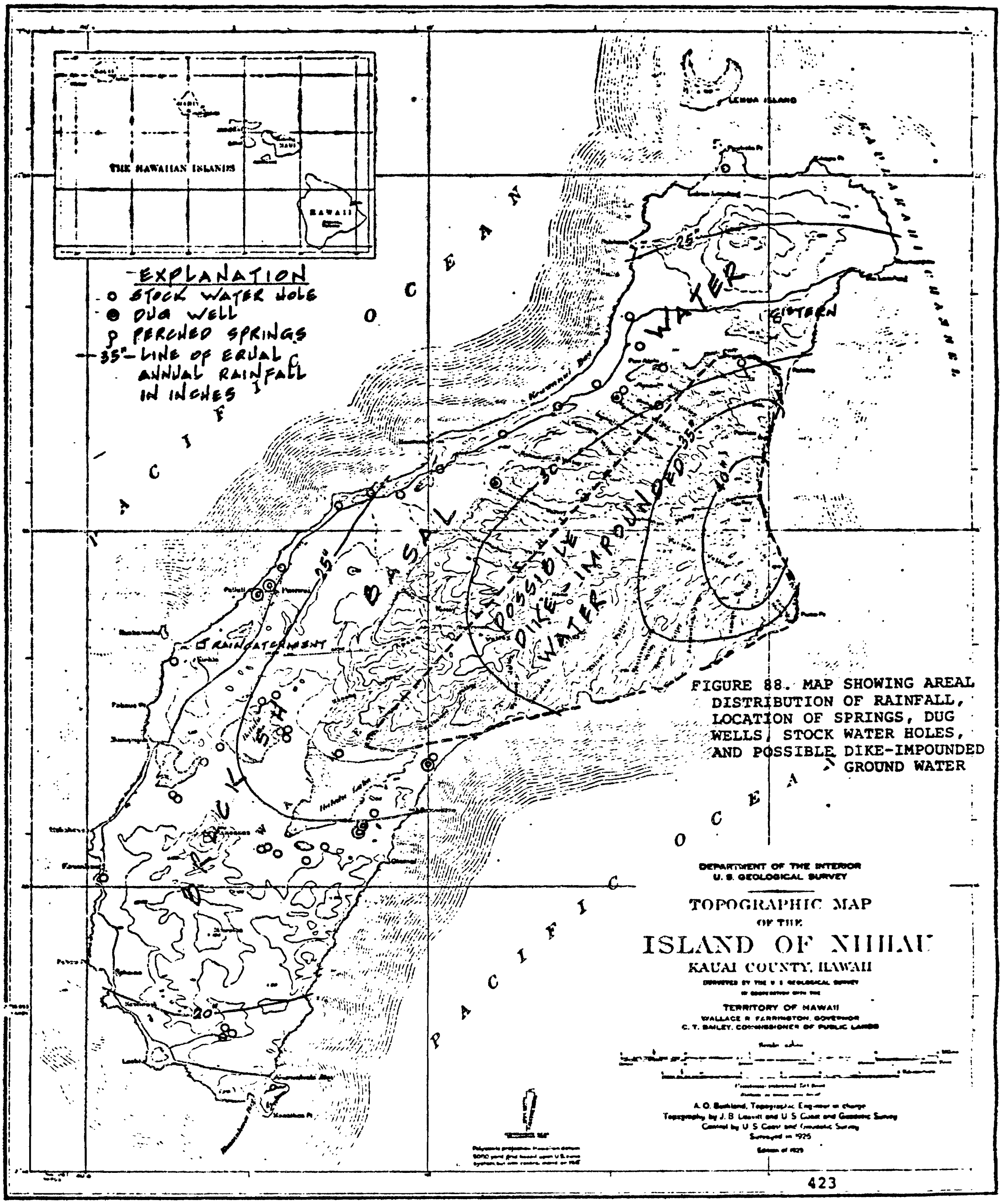


FIGURE 88. MAP SHOWING AREAL DISTRIBUTION OF RAINFALL, LOCATION OF SPRINGS, DUG WELLS, STOCK WATER HOLES, AND POSSIBLE DIKE-IMPOUNDED GROUND WATER

The sources of salt are the ocean, salt in lake deposits, and salt spray. The salinity of ground water, because of the different sources of salt, is often unpredictable, because it depends much on the proximity of the sources rather than distance from the ocean, as in the case generally.

Wells yielding the best quality water were those dug in unconsolidated dune sands. The poorest wells are in alluvium and silt where the rocks contain salts deposited by evaporation of the playa lakes. Beach sands are highly permeable, but they generally yield water too salty for stock.

Dike-Impounded Water

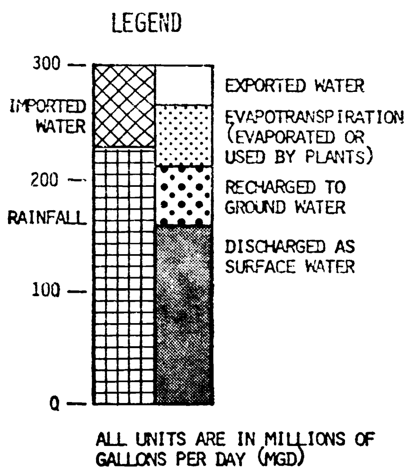
The largest undeveloped supply, according to Stearns (1947), probably lies between the dikes in the basalt of the Paniau Volcanic Series.

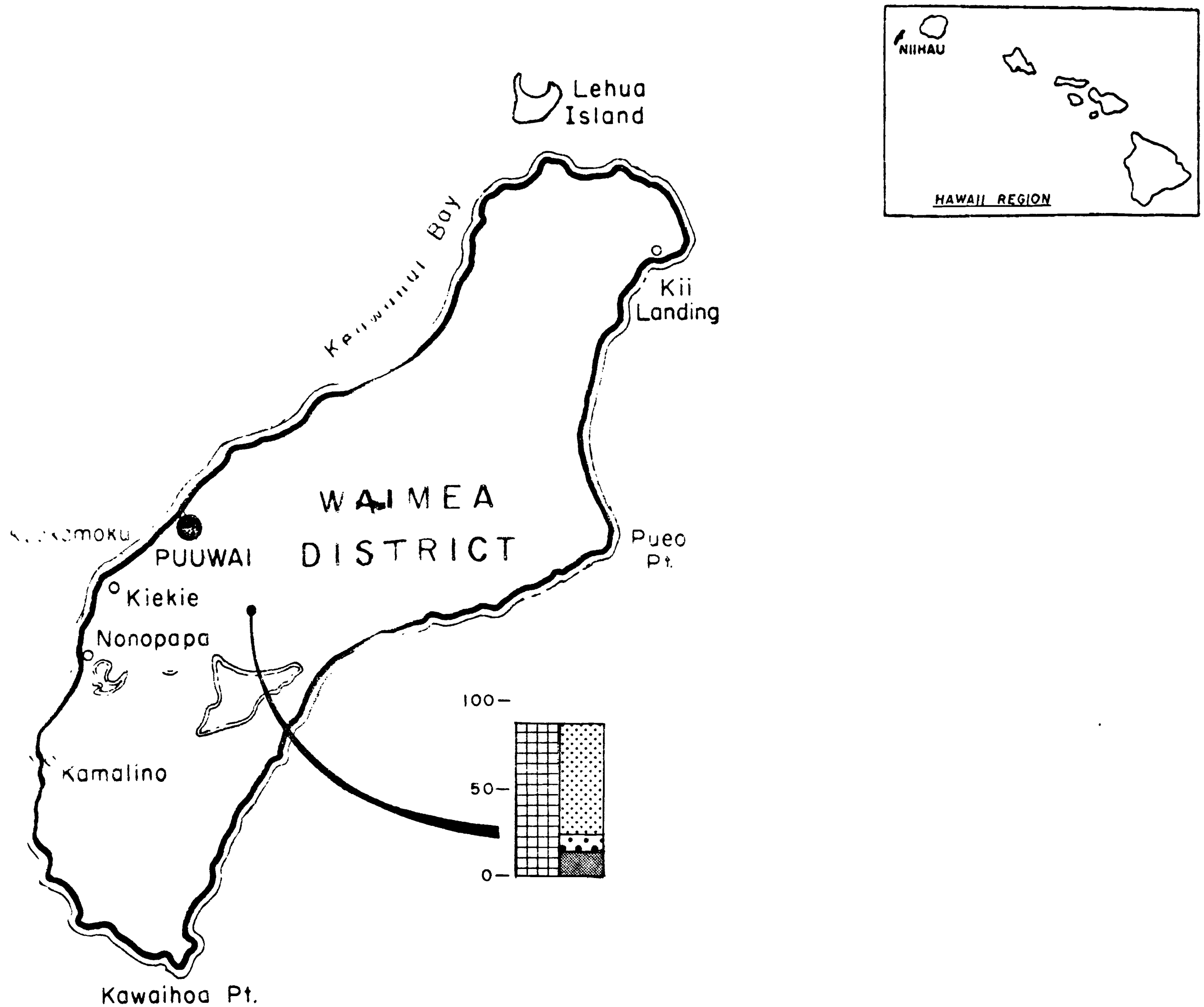
Most of the dikes in the basalt trend southwestward, and this causes ground water to move in that direction.

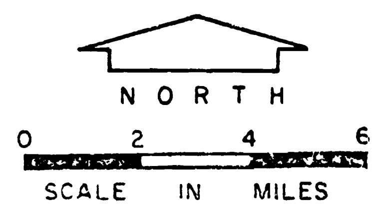
Perched Water

Perched-water bodies are small. The salt content of springs discharging from perched-water bodies is unusually high, owing to salt spray. The salt, carried inland by the wind, is deposited on the surface at high altitudes and later leached by percolating waters.

Figure 89 shows the occurrence of water on Niihau.







SUBREGION 8
ISLAND OF NIIHAU

FIGURE 89. WATER OCCURRENCE, NIIHAU

Quality of Water

Niihau has no perennial streams, but has small lakes and several springs. During heavy precipitation, most lakes are filled with fresh flood waters. The fresh water soon evaporates, leaving brackish water, and eventually, salt deposits.

The perennial springs yield poor-quality water. The chloride concentrations of Waiakaulili and Kaali Springs are 467 mg/l and 378 mg/l, respectively. The waters are captured for stock use.

Ground-water quality is poor. Dissolved solids of most basal water are beyond recommended drinking standards. Stearns (1947) reported only three wells that yield good-quality water, but the quantities are small, and the prospect of developing good drinking water on Niihau is poor.

Present Use of Water

Ground water is used for cooking, washing, and for stock. The water is obtained from dug wells and stock-water holes. Stock-water holes are dug so that stock can enter them, and differ from dug wells, which are generally curbed.

There is no information on the total quantity of water used on the island. The owners supplied the following information with respect to individual livestock water needs on the island. Horses consume 10 to 15 gallons of water daily, cattle consume 15 to 20 gallons daily, and sheep about 1 gallon daily.

Population is about 270 and drinking water is caught on the roofs, and in extremely dry weather, water is imported from Kauai. Laundry is done with brackish well water or seawater.

Potentials for Development

The prospects of developing large quantities of fresh water are small, owing to the generally low recharge from rain, the deeply weathered nature of surface rocks in the rainier areas, the less than ideal oblong shape of the island, and the varied sources of salt.

The prospects are very poor for developing domestic-quality basal-water supplies. However, limited supplies of water fit for cooking, washing, and stock are probably available with careful development and management. The most promising areas appear to be in areas that border the western and southern flanks of the volcanic dome. These areas receive runoff from the mountainous areas.

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